

INTEGRATION OF V2V-AEB SYSTEM WITH WEARABLE CARDIAC
MONITORING SYSTEM AND REDUCTION OF V2V-AEB SYSTEM TIME
CONSTRAINTS

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To follow every path one needs some light. I would like to thank all the people who were my lights.

I want to thank and dedicate my thesis to my family and my advisor. A special gratitude to my loving and supporting parents Rashmi Bhatnagar and Rakesh Bhatnagar who taught me the meaning of life and never giving up attitude. My sister Trisha Srivastava and my brother Sarvesh Bhatnagar never left my side and were always there when I needed someone. I am fortunate to have such a great loving parents and family who have groomed me and helped me at every step of life.

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TABLE OF CONTENTS

	Page
LIST OF TABLES	vii
LIST OF FIGURES	viii
SYMBOLS	x
ABBREVIATIONS	xi
ABSTRACT	xii
1 INTRODUCTION	1
1.1 Background	4
1.1.1 Vehicle to Vehicle Communication	4
1.1.2 Autonomous Emergency Braking	6
1.2 V2V-AEB System	7
1.2.1 PreScan	9
1.2.2 V2V-AEB Architecture	11
1.2.3 V2V-AEB Simulation Model	14
1.3 Thesis Organization	14
2 INTEGRATING V2V-AEB WITH CARDIAC MONITORING SYSTEM . .	17
2.1 Literature Review	18
2.2 Methodology	19
2.3 Analyze the Pre-recorded Dataset	21
2.3.1 Bifurcate the pulse rates of a particular user according to mo- tion types.	22
2.3.2 Find normal and abnormal heart beat patterns	29
2.3.3 Verification of abnormal heart rate	32
2.4 Adapting Intelligent Cardiac Monitoring system in V2V-AEB	36
2.4.1 Simulation	38

	Page
2.4.2 Hardware Model	39
3 EFFECT OF DELAY IN V2V-AEB	43
3.1 Mathematical Model to Reduce Effect of Delay	46
3.2 Algorithm to Reduce Effect of Delay	56
3.3 Result	58
4 HANDLING DELAY IN V2V-AEB	61
4.1 Optimizing Vehicle Information	62
4.2 Optimizing Pedestrian Information	63
4.3 Grouping of Pedestrians	69
4.3.1 Working of the system	70
4.3.2 Result	74
4.4 Jamming of Network	74
4.5 Message Confidence	78
5 CONCLUSION AND FUTURE WORK	80
5.1 Conclusion	80
5.2 Contributions	81
5.3 Future work	82
REFERENCES	83

LIST OF TABLES

Table	Page
1.1 Types of time delay in V2V-AEB	3
1.2 Standard applications of V2V	5
2.1 Table for average heart rates [26]	30
2.2 Matrix A: to study the abnormality in heart rate	33
3.1 Bifurcation of delay (D)	44
3.2 Algorithm to reduce effect of delay	57
4.1 Algorithm to determine which pedestrian information should be sent . . .	69
4.2 Matrix for pedestrian information	71

LIST OF FIGURES

Figure	Page
1.1 The advantages of V2V-PAEB system	9
1.2 Overview of the V2V-AEB system	10
1.3 The architecture of the V2V-AEB system	12
1.4 The V2V-PAEB Simulation model	15
1.5 The V2V-AEB simulation scenario	16
2.1 Processing unit of Cardiac monitoring system.	20
2.2 Acceleration sensor data	24
2.3 A KNN algorithm example	24
2.4 Normalization of relative acceleration	27
2.5 Classification using the KNN algorithm from relative acceleration	28
2.6 Detailed system diagram	34
2.7 Heart attack detection	35
2.8 Integration of V2V-AEB and Intelligent cardiac monitoring system	36
2.9 Implementation process of Cardiac Monitoring System(Trigger signal-Time)	38
2.10 Heart rate sensor module	40
2.11 Connection of heart rate sensor module with FRDM K-64	41
2.12 Real time pulse rate using FRDM K64	42
3.1 Vehicle's ttb, tsb and ttc	47
3.2 The scenarios of vehicles with V2V-AEB enabled system.	48
3.3 Pedestrian tracking to calculate ttc.	48
3.4 Pedestrian tracking to calculate ttc with and without delay	50
3.5 To calculate ttb to stop at a distance (d) before collision	54
3.6 Block diagram to reduce effect of delay	57
3.7 V2V-AEB simulation	59

Figure	Page
3.8 Result of primitive method and proposed method	60
4.1 Location from Google map	64
4.2 Sending information of the pedestrian in front	65
4.3 Block diagram to determine which pedestrian information should be sent .	68
4.4 Pedestrian detection by the vehicle	70
4.5 Example of pedestrian groping	72
4.6 Algorithm for clustering	75
4.7 Grouping of pedestrians using MATLAB (blue dots indicate the hub) . . .	76
4.8 Block diagram to reduce jamming of the network	78

SYMBOLS

A	resultant acceleration
A_r	acceleration sensor value while running
A_{re}	acceleration sensor value while resting
A_w	acceleration sensor value while walking
D_c	signal transmission delay (communication delay)
D_m	mechanical delay
D_p	signal processing delay
D_s	sender delay
$max(A)$	maximum value of resultant acceleration for an activity
$min(A)$	minimum value of resultant acceleration for an activity
NA	normalized value of acceleration
S_v	maximum distance to decide whether to send the message or not
t_a	time difference between original time to collision and current time to collision
t_d	time delay
ttc_c	current time to collision after prediction
ttc_o	original time to collision without prediction
V_c	velocity of the car
V_p	velocity of the pedestrian
V_r	relative velocity

ABBREVIATIONS

AEB	Autonomous Emergency Braking
M_d	Maximum delay
$Ntsb$	New tsb
PAEB	Pedestrian Autonomous Emergency Braking
tsb	Time to start braking
ttc	Time to collision
ttb	Time threshold for braking
ttb_s	ttb to stop d distance before collision
V2V	Vehicle to Vehicle
V2V-AEB	Vehicle to Vehicle Communication and Autonomous Emergency Braking
V2V-PAEB	Vehicle to Vehicle Communication and Pedestrian Autonomous Emergency Braking

ABSTRACT

Bhatnagar, Shalabh. M.S.E.C.E., Purdue University, August 2017. Integration of V2V-AEB System with Wearable Cardiac Monitoring System and Reduction of V2V-AEB System Time Constraints. Major Professor: Stanley Chien.

Autonomous Emergency Braking (AEB) system uses vehicles on-board sensors such as radar, LIDAR, camera, infrared, etc. to detect the potential collisions, alert the driver and make safety braking decision to avoid a potential collision. Its limitation is that it requires clear line-of-sight to detect what is in front of the vehicle. Whereas, in current V2V (vehicle-to-vehicle communication) systems, vehicles communicate with each other over a wireless network and share information about their states. Thus the safety of a V2V system is limited to the vehicles with communication capabilities. Our idea is to integrate the complementary capabilities of V2V and AEB systems together to overcome the limitations of V2V and AEB systems. In a V2V-AEB system, vehicles exchange data about the objects information detected by their onboard sensors along with their locations, speeds, and movements. The object information detected by a vehicle and the information received through the V2V network is processed by the AEB system of the subject vehicle. If there is an imminent crash, the AEB system alerts the driver or applies the brake automatically in critical conditions to prevent the collision.

To make V2V-AEB system advance, we have developed an intelligent heart Monitoring system and integrated it with the V2V-AEB system of the vehicle. The advancement of wearable and implantable sensors enables them to communicate drivers health conditions with PCs and handheld devices. Part of this thesis work concentrates on monitoring the drivers heart status in real time by using fitness tracker. In the case of a critical health condition such as the cardiac arrest of a driver, the

system informs the vehicle to take an appropriate operation decision and broadcast emergency messages over the V2V network. Thus making other vehicles and emergency services aware of the emergency condition, which can help a driver to get immediate medical attention and prevent accident casualties.

To ensure that the effectiveness of the V2V-AEB system is not reduced by a time delay, it is necessary to study the effect of delay thoroughly and to handle them properly. One common practice to control the delayed vehicle trajectory information is to extrapolate trajectory to the current time. We have put forward a dynamic system that can help to reduce the effect of delay in different environments without extrapolating trajectory of the pedestrian. This method dynamically controls the AEB start braking time according to the estimated delay time in the scenario.

This thesis also addresses the problem of communication overload caused by V2V-AEB system. If there are n vehicles in a V2V network and each vehicle detects m objects, the message density in the V2V network will be $n \times m$. Processing these many messages by the receiving vehicle will take considerable computation power and cause a delay in making the braking decision. To prevent flooding of messages in V2V-AEB system, some approaches are suggested to reduce the number of messages in the V2V network that include not sending information of objects that do not cause a potential collision and grouping the object information in messages.

1. INTRODUCTION

According to WHO (World Health Organization), lives of approximately 1.27 million people are cut short every year as a result of a road traffic crash. Half of the 1.27 million people die in road traffic crashes are pedestrians, motorcyclists, and bicyclists [1]. In TASI (Transportation Active Safety Institute) at IUPUI, our focus lies on research to reduce the road accidents and make the road safer.

Various advancements have been achieved in the field of active Safety systems to make the road safer. V2V communication, Adaptive Cruise Control, and Automatic Emergency Braking are some of the advances in the active safety systems. In the current V2V (vehicle to vehicle communication) system, vehicles communicate with each other over a wireless network. A standard protocol for a V2V wireless network is Discrete Short Range Communication (DSRC) [2]. Each vehicle in the V2V system acts as a communication node. It exchanges data about its location, speed, and movement and makes the decision, based on received information accordingly [2]. Its limitation is, it only broadcasts about what is going on in the system [2]. So the safety is limited to vehicles in the V2V network.

Whereas AEB (Autonomous Emergency Braking) system uses vehicle's on-board sensors such as radar, LIDAR, camera, infrared, etc. to detect and alert the driver for any potential collision [3]. Its limitation is that it requires clear line-of-sight to identify the objects in the surrounding [4]. Our idea is to integrate the complementary capabilities of V2V and AEB systems to overcome the personal limitations of V2V and AEB systems. In V2V-AEB, vehicles exchange data about the objects information detected by its onboard sensors and its location, speed, and movement.

The object information detected by a vehicle and the information received through the V2V network is processed by the AEB system of the vehicle. If there is an imminent crash, the AEB system alerts the driver and applies the brake automatically in critical condition.

Moreover, rapid growth in health monitoring systems has enabled us to integrate these technologies with V2V-AEB system to improve safety. So far, the research of health-related mobile applications have focused on measuring the pulse rate, blood sugar levels, cholesterol, distance walked/stairs climbed, diet suggestions, calories burnt etc. [5] [6]. We have concentrated on developing an intelligent heart monitoring system to detect medical emergencies such as paralytic attack, cardiac arrest, etc. by studying the frequency of the pulse rate from the fitness tracker. When a vehicle gets the medical emergency information, it broadcasts the message on V2V network with higher priority and tries to apply brake using AEB system to stop safely. Moreover, it informs emergency services so that the driver can get a quick medical attention.

For a practical implementation of the V2V-AEB system, it is necessary to resolve certain issues. One of the key issues is a time delay in the system. As in real time V2V-AEB system, delays [as shown in Table 1.1] may be caused during the period of detection, communication, processing and while implementing the decision at the sender as well as at the receiver side. This delay will result in a late response by the AEB system which may lead to a collision. For the system to function correctly, the delay in the system should not exceed an absolute limit. If the delay is too long, the receiving vehicle may not have enough time to respond to the received information. Hence the shared AEB information may become useless.

To make a system robust such that delay in the system does not reduce its effectiveness while making a decision, it is necessary to study the effect of delay thoroughly and to handle them properly. One common practice to control the delayed trajectory information is to extrapolate trajectory to the current time. We have put forward a dynamic system that can help to reduce the effect of delay in different environments

Table 1.1.
Types of time delay in V2V-AEB

Time Delay type	Definition
Sender delay	It occurs while detecting pedestrian through AEB system on the sender side and merging all the information of detected object in a message format.
Communication delay	It occurs during transmitting data from one object to another. This may occur due to packet collision or excess of information in the network.
Mechanical delay	It happens in the braking system. It represents the time difference between good and bad mechanical operation due to change in friction between road and tire.
Signal processing delay	Occurs, while processing and merging the information, received from other vehicles and its sensors, for making AEB decision.

without extrapolating trajectory of the pedestrian. However, when the delay is above certain time, the system fails to overcome that delay. So it's necessary to keep the delay under a particular value. To reduce delay in V2V-AEB, various methods have been proposed and implemented. The proposed method helps to reduce communication delay, delay due to packet collision and signal processing delay by decreasing the number of messages in the V2V-AEB system. By preventing from sending messages related to the pedestrian who likely will not cause a collision (like the pedestrian who are walking on the sidewalk and who are standing off the road).

The other method developed, is grouping the pedestrians with similar features in one message, thus reducing the number of messages in the system and decreasing the communication and signal processing delay. Before going further let's learn more about V2V, AEB, and V2V-AEB systems.

1.1 Background

1.1.1 Vehicle to Vehicle Communication

Vehicle to vehicle communication is a type of Internet of things designed to connect the vehicles with each other. V2V communication enables the vehicles to share its information such as its position, speed, steering wheel position, brake status, and other vehicle dynamics over V2V network [2]. The information shared over V2V network can be used effectively to avoid road accidents and to deal with traffic congestion. For example, the vehicle can detect other vehicles which are in blind spots using V2V communication or it can help the driver to select a path with minimum traffic congestion.

Vehicles use Dedicated Short Range Communication (DSRC) media to communicate with other vehicles in the V2V network. DSRC is a two-way wireless communication; it is a short range to medium range communication, which helps vehicles to share information at a very high transmission rate and with the low latency, which is a vital requirement for an active safety application [2]. The federal communication commission that regulates interstate communication signal has allocated 75MHz spectrum from the 5.9GHz band for V2V communication in the US.

The range of DSRC is about 1000 meters. Thus the vehicles can communicate with other vehicles in the range of 1000 meters [7]. In V2V each vehicle's behaves as a communication node and exchange information with other nodes. The vehicle collects and uses the excessive amount of data from a huge array of sources to make a safety decision.

With vehicles in the surrounding area, V2V provides the driver with 360 degrees of awareness. The effect of obstacles on radio message is not adverse. Therefore it is not necessary that the objects should be in the range of the vehicle sensors to detect emergencies. Research by NHTSA estimates that V2V communication can help the driver to prevent 70 percent to 80 percent accidents of unimpaired drivers [8].

Few, applications of V2V system [9] is shown below (Table 1.2):

Table 1.2.
Standard applications of V2V

Blind spot detection
Forward collision warning
Sudden braking ahead warning
Do not pass warning
Intersection collision avoidance and movement assistance
Approaching emergency vehicle warnings
Vehicle safety inspection
Transit or emergency vehicle signal priority
In-vehicle signing
Rollover warning
Traffic and travel condition data to improve traveler information and maintenance services

The limitation of V2V is that it only shares the information about vehicle's state, such as its position, velocity, whether it's going to take a turn or apply a brake. Thus the safety due to V2V remains for the vehicles with the capability of V2V communication.

1.1.2 Autonomous Emergency Braking

There has been a huge advancement in active safety features. AEB has been one of the vital parts of active safety systems development. AEB system is designed to alert the driver in emergency conditions and take the braking decisions if the driver does not make the desired decision to prevent a potential collision. A study performed by IIHS (Insurance Institute for Highway Safety) shows that AEB system can reduce rear-end collision around forty percent by 2025. NHTSA has announced automakers to make AEB system as a standard feature by 2022 claiming that it can prevent 28,000 crashes and 12,000 injuries [8].

Pedestrian Autonomous Emergency Braking (PAEB) is an important part of the AEB system. The PAEB system calculates the probability of collision with a pedestrian by processing the position and relative speed of pedestrian with respect to vehicles current position. AEB system uses different types of sensors to detect the potential collision, such as radar, LIDAR, and camera [3]. The system processes the information provided by the onboard sensors of the vehicle and its current state (vehicle position, speed, direction, etc.), to recognize all potential collisions. To apply automatic brake some system uses full braking pressure, while other use elevated braking pressure proportional to the emergency level to prevent a possible collision.

Furthermore, to improve the efficiency of AEB system some companies use automatic steering along with automatic braking to avoid collision [10]. For example, if there is a case when there is not enough room to avoid a collision by just applying the brake, the system can use automatic steering along with the brake to prevent the collision.

Suppose a case when a vehicle is moving at high speed, and the vehicles AEB system detects a potential collision with a pedestrian, which is crossing the road. The AEB system will then inform the driver to take the desired action.

However, if a vehicle finds the probability that by just applying brake it cannot prevent a collision, AEB will start the automatic steer assist along with brake to move vehicle away from the pedestrian to avoid an accident. The AEB system has helped us to reduce the number of accidents by a considerable amount.

There are few limitations of the AEB system; Like, the sensors in the vehicle require a clear line of sight. If the object is not in a line of sight of the sensor, the vehicle will not be able to detect a potential collision.

1.2 V2V-AEB System

To overcome the limitations of the V2V and the AEB system as mentioned above, we have integrated the complementary capabilities of the V2V and the AEB system by sharing the information detected by the vehicles onboard sensor over the V2V network [11]. The other vehicles can use this information to make a safety decision if necessary. Thus, it compensates the limitations and disadvantages of both the V2V system and the AEB system as mentioned below [11].

For an AEB system to detect a pedestrian, it is necessary that the pedestrian is in its line of sight. These limitations of the AEB system might be nullified by the proposed V2V-AEB method, as vehicles can use the information sent by other vehicles. Another limitation of AEB system is that its sensors have short detection range, which provides little time for the system to react. The maximum detection range of AEB sensor is 80-100 meters. Beyond this, it is difficult for the vehicle to detect objects. However, as the range of the V2V is 1000 meters, sharing the AEB information over the V2V network can extensively increase the detection range of objects. Moreover, AEB system might have sensor limitations under some particular condition. In such case, the vehicle can use the shared information from the other vehicles AEB system in V2V network.

Along with V2V enabled vehicles, V2V-AEB system also helps non-V2X enabled objects such as pedestrians. Research is going on to build a device with which pedes-

trian can broadcast their information to the vehicles in the V2X system for safety. However, this system can only help the pedestrian with a V2X facility. Whereas, V2V-AEB system does not require the pedestrian to have any such device. So comparing with other technologies V2V-AEB system can also help both V2V as well as non-V2X enabled vehicles.

The Fig. 1.1 as shown below, gives an example showing advantages of a V2V-AEB system. Suppose all the vehicles are equipped with the V2V-PAEB system, and a pedestrian is crossing the road. The pedestrian is not in the line of sight of a car, but the AEB system of the truck can detect a pedestrian, the truck broadcasts the pedestrian information on the V2V network. All vehicles receiving this information can make a safety decision. If the V2V-AEB system were not there, the car would not know that the pedestrians are crossing the road and there might be a collision.

We have seen the working of the V2V-AEB system and its advantages. Let us look at the basic architecture of the V2V-AEB enabled vehicle as shown in Fig. 1.2.

The overview of an V2V-PAEB system is shown below in the Fig. 1.2. For a better understanding, we can divide the system in two-parts i.e. sender side and receiver side.

Sender side: The PAEB system processes the data from the camera sensor and the radar sensor. If there are any pedestrians in the scenario, the PAEB system senses the pedestrians and collects its information. Then the information is passed to the following blocks: here the data is converted into global coordinates from local coordinates of the respective vehicle, and it is given to the AEB system to make the desired decision to prevent a potential collision. Then the information is formulated in the message format along with the vehicle state. The vehicle broadcasts this message over the V2V network.

Receiver side: The message (V2V-PAEB) received by the vehicle is processed and merged, as different vehicles may send the information of the same pedestrian. Then the pedestrian information is converted into local coordinate of the respective vehicle. Message merge block combines the information of the pedestrians from V2V with the

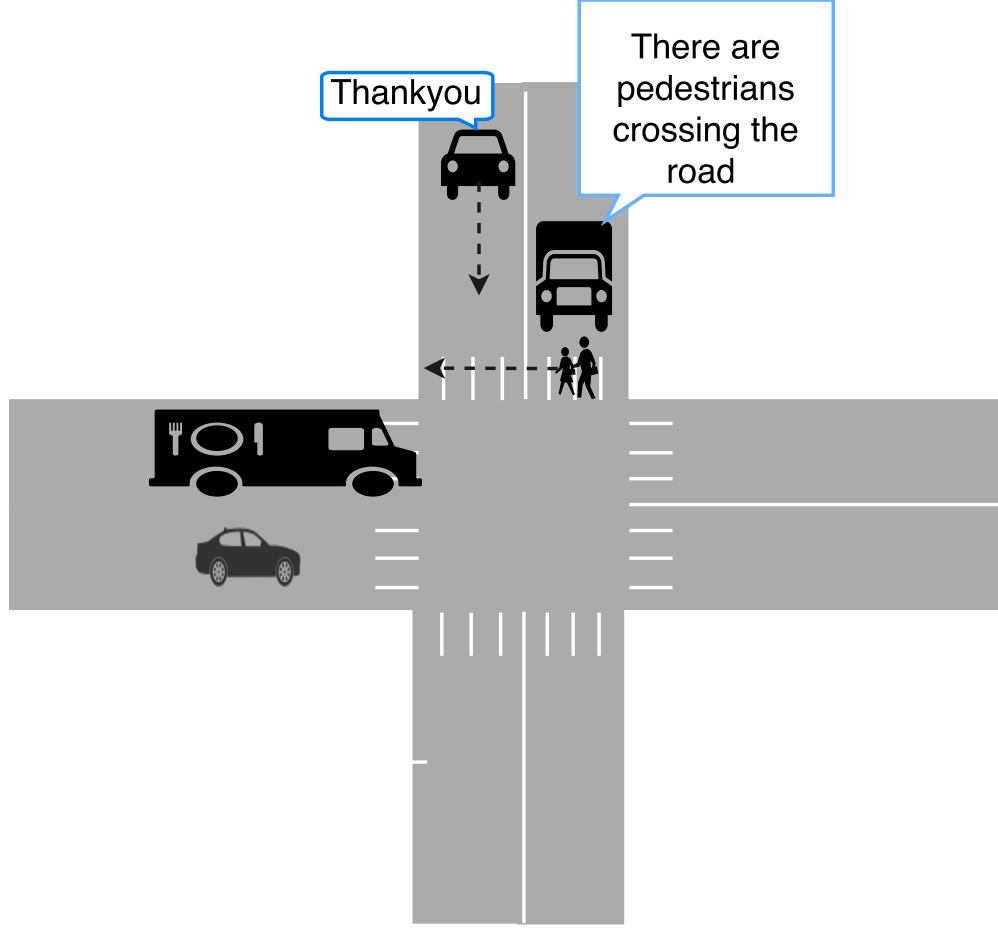


Fig. 1.1. The advantages of V2V-PAEB system

information of the pedestrians provided by its PAEB system. Then the pedestrian is tracked and time to collision of the pedestrian with respect to the vehicle is calculated to make the desired decision.

1.2.1 PreScan

To simulate scenarios and to test the proposed method we have used a Prescan software provided by the TASS International company. PreScan is a physics based simulation platform; it is designed as a development tool for the advanced driver safety system (ADAS) and the intelligent vehicles system [12]. It can be used to simulate

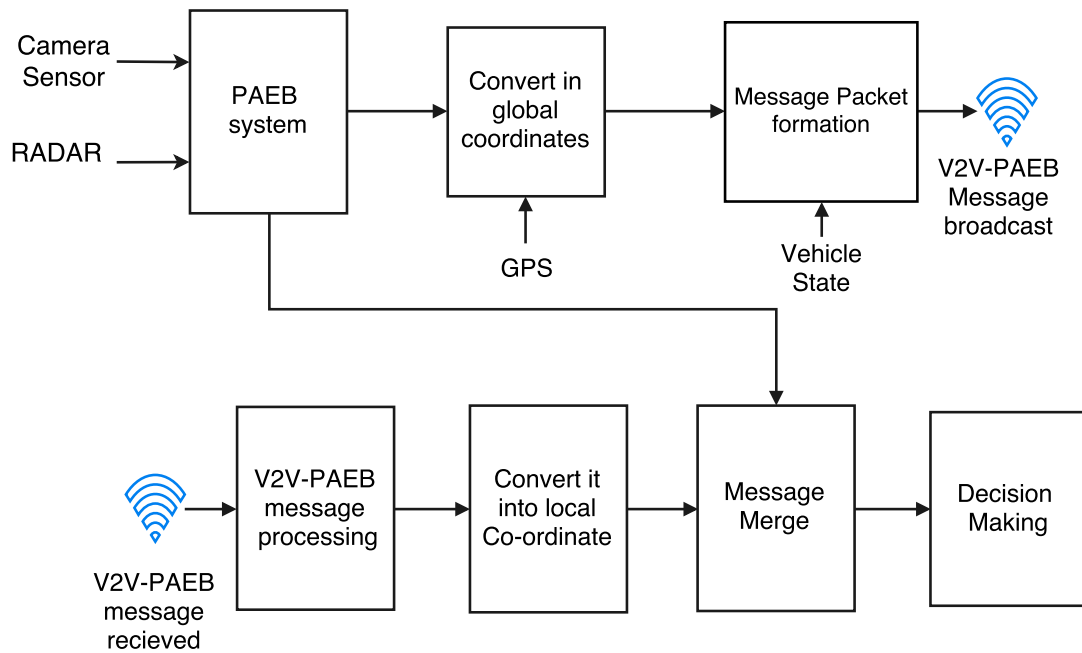


Fig. 1.2. Overview of the V2V-AEB system

the operation of an intelligent vehicle system using various sensor technologies such as radar, LIDAR, camera, ultrasonic and GPS systems. It is used by many automobile industries to develop such system. It also provides a framework for a V2V and the V2I technologies. Thus empowering a user to develop, design and evaluate various V2V applications.

PreScan provides a dedicated graphical user interface (GUI) that enable users to build and develop the traffic scenarios. It offers various features, such as: road sections, infrastructure components (building, street light, traffic signals, etc.), actors (Pedestrians, Car, Truck, Motor Bike, etc.), lighting conditions (Day, Sunlight, Night. Headlights and lampposts) and weather conditions (Rain, Snow, Fog, etc.).

It enables a user to design, develop and verify the algorithms for data processing, sensor fusion, decision making using Matlab/Simulink interface. PreScan also provides a 3-D visualization of the generated scenario and the developed method, for the user to visualize it.

Since PreScan is a physics-based simulation, it provides an insight of how the system will behave in actual conditions. Also, it provides various other benefits such as 3D view. The user can also modify the weather, lightning, and a road friction state quickly. It also provides an ability to the user to control actors dynamic easily. Thus, we used PreScan to develop the proposed methods and study it.

1.2.2 V2V-AEB Architecture

The proposed methods are implemented using MATLAB/Simulink. Various scenarios are developed to test the proposed methods [11]. The time delay in the systems was studied. Several algorithms are proposed and implemented to reduce the effect of delays in the V2V-PAEB system. Before moving forward let's look into the architecture (Fig 1.3.) of the proposed method.

The information processing stages are summarized as follows:

- a. Sensor data preprocessing - The input of this block are raw data from the onboard sensor of the vehicle. It processes the raw data and calculates the region of interest (ROI) using a fast algorithm to detect a possible pedestrian in the system. The list of the entire possible pedestrian detected is sent to the next block to bifurcate pedestrians with other objects as it may have a false alarm.
- b. Pedestrian Detection - This stage has a more sophisticated algorithm to distinguish the pedestrians from the non-pedestrian objects by studying their ROI provided by the previous stage.
- c. Tracking - We track and calculate the direction, trajectory, speed, acceleration and location in GPS coordinate for every detected pedestrian.

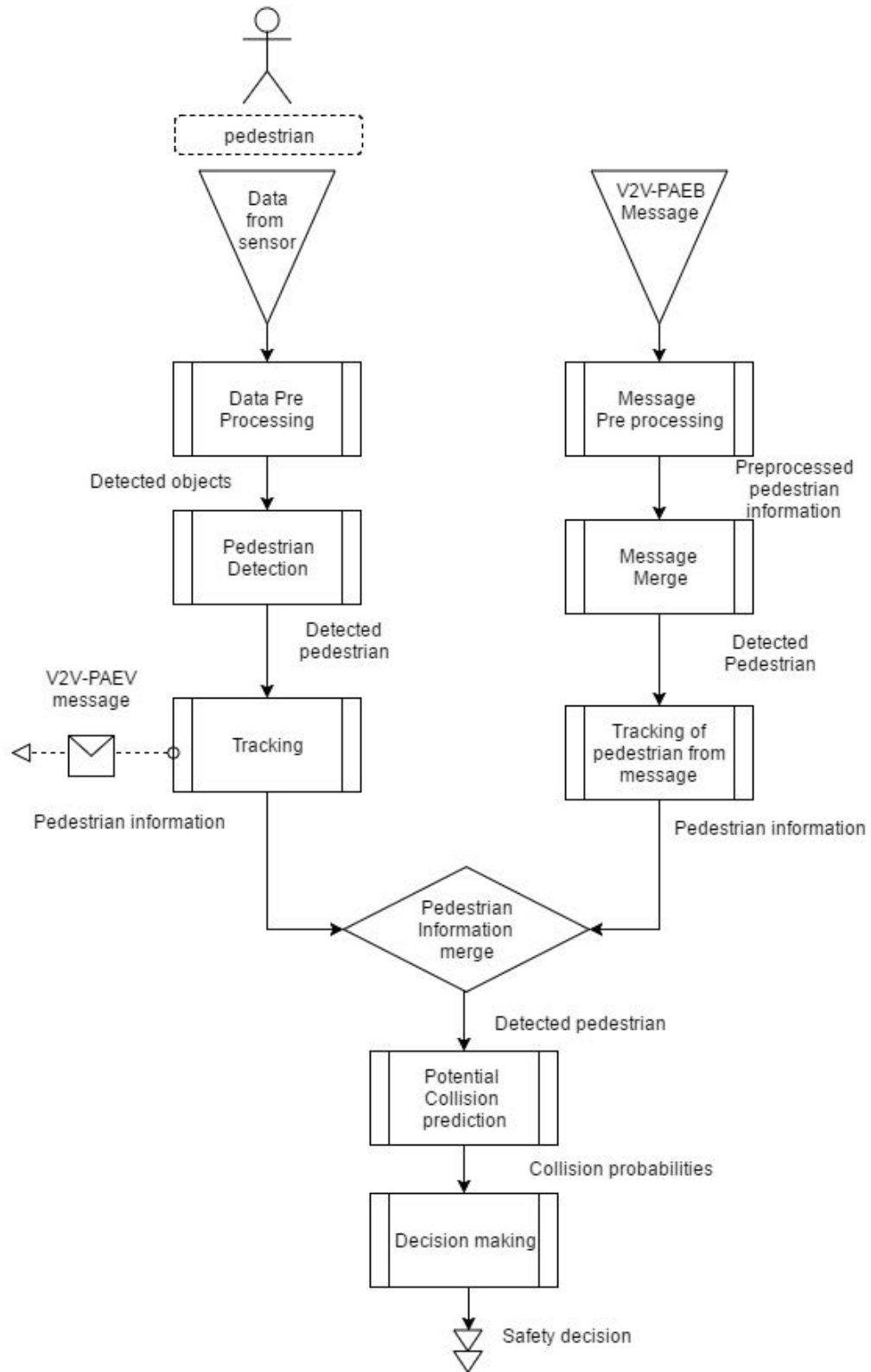


Fig. 1.3. The architecture of the V2V-AEB system

d. Send V2V-AEB message - All the information is being converted into message format to broadcast in the V2V network.

e. V2V-AEB message preprocessing - The received messages are placed in a queue periodically. Then the message is read from the queue, and the pedestrian information is extracted such as its speed, and the location.

f. V2V-AEB message merge - The extracted data from the received message is merged to obtain a list of pedestrians without duplicate ones. The information of each pedestrian should be accurate.

g. Tracking 2 - All the pedestrian information received from the V2V-AEB messages are tracked over time to get their trajectories to predict their future locations.

h. Pedestrian Information merge - The pedestrian information from vehicles onboard sensors and those we got from the V2V-AEB system is merged to obtain a complete set of pedestrians surrounding the host vehicle.

i. Potential Collision Prediction - This stage projects the current trajectories of pedestrians and host vehicles into future and determines the possibility of collision based on geometric computations.

j. Decision making - This stage is responsible for making the proper safety decisions when potential collisions are detected. It makes the safety decision by generating a warning signal to the driver in case of a possible collision or by applying the brake in the event of an imminent crash.

1.2.3 V2V-AEB Simulation Model

Based on the detailed architecture the model was designed using a PreScan in Matlab and Simulink. The simulation model is shown below in Figure 1.4. The developed simulation model was tested on the scenario as shown below in the Fig. 1.5. In the scenario as shown in Fig. 1.5, the speed of the car is $14m/s$, the deceleration of the car is $12m/s^2$ and the speed of right (men) and left (woman) pedestrians is $1.5m/s$ and $2m/s$, respectively.

The pedestrians are not visible to the red car because its line of sight is obscured by the truck. Thus, the red car won't know that the pedestrians are crossing the road this may lead to an accident. However, the truck and the green car can detect both pedestrians and broadcast their information. This information received through a V2V network can be used by the red car to make a safety decision as seen in Fig. 1.5 (b) and (c).

1.3 Thesis Organization

After studying about the V2V, AEB, and the V2V-AEB system let us go ahead. V2V-PAEB system helps us to protect pedestrians and objects in the surrounding of the vehicle. But what if the driver is in some medical emergency? To answer this question and make more advanced active safety features, we integrated the intelligent cardiac monitoring system with the V2V-AEB system, which will be seen in section 2 of this thesis. For a more reliable active safety system, it is necessary to reduce the latency in the V2V-AEB system. Thus, section 3 will focus on studying delay in the V2V-PAEB system, and a model will be discussed to reduce the effect of delay. It is found out, that even after using the proposed method to lessen the impact of delay in the system, when the delay goes above the threshold value the system fails. Thus, section 4 will introduce some methods to reduce delay in the V2V-AEB system [13].

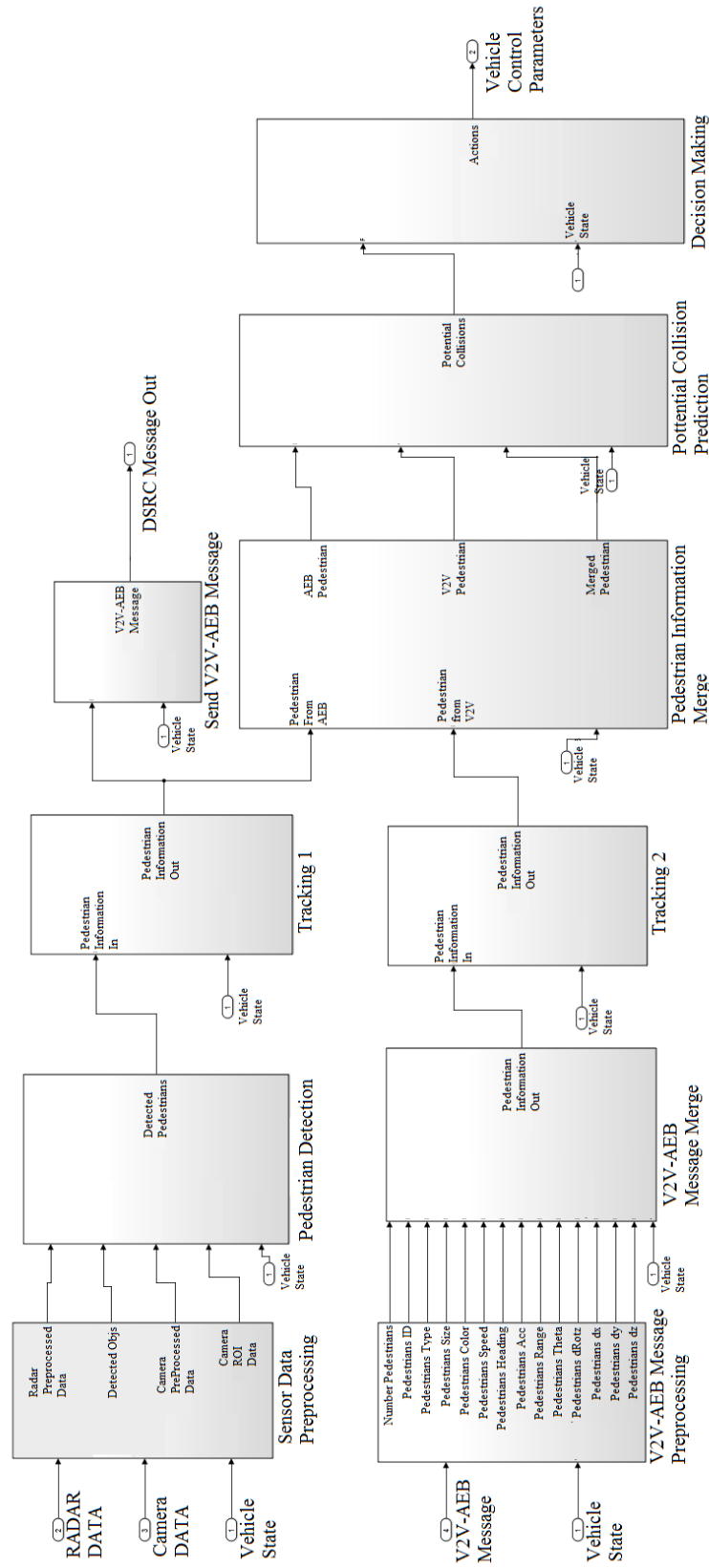
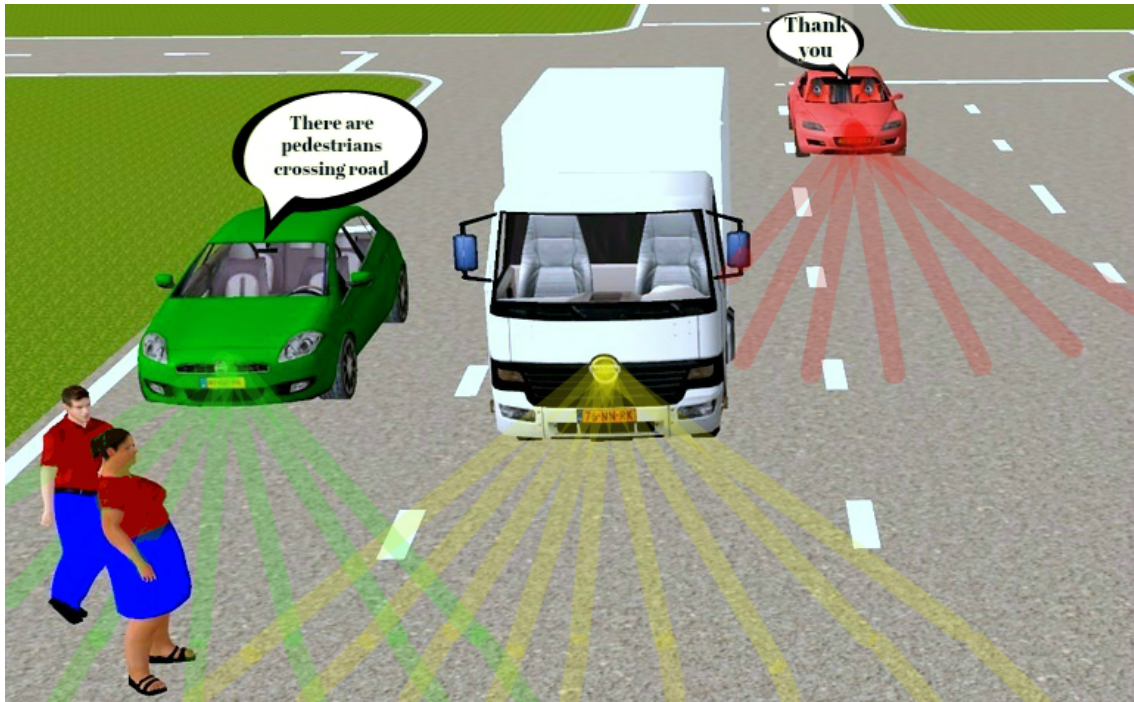
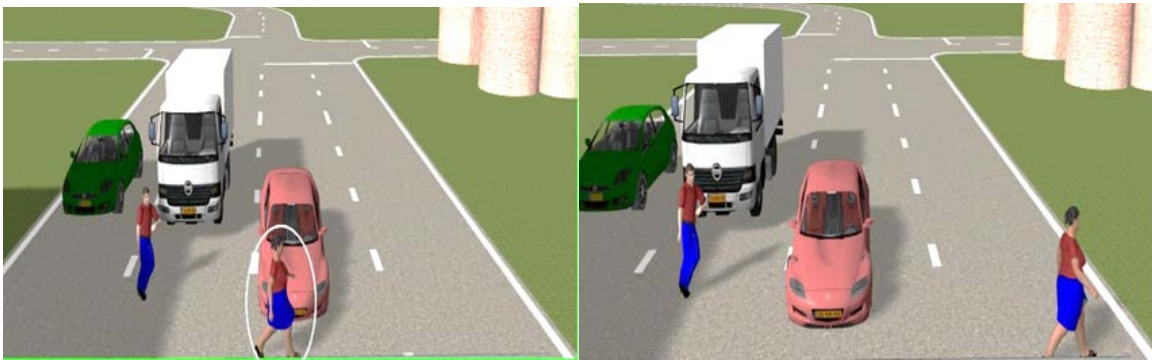


Fig. 1.4. The V2V-PAEB Simulation model



(a) V2V-PAEB test scenario



(b) The front view when vehicles started applying break using V2V-AEB system
 (c) The front view after pedestrian crossed the road safely

Fig. 1.5. The V2V-AEB simulation scenario

2. INTEGRATING V2V-AEB WITH CARDIAC MONITORING SYSTEM

The proposed V2V-AEB system helps us to protect pedestrians and the object in the surrounding of the vehicle. However, it does not provide the information related to whereabouts of drivers condition such as his health status. To take it one step ahead we have proposed a method to monitor the drivers health condition and inform the vehicle in case of a medical emergency.

Rapid growth in the advanced active safety systems and the health monitoring systems have enabled the possible integration of these technologies for improved vehicle safety. In the V2V-AEB system, the vehicle shares its information and the environment information detected by its onboard sensor over V2V network, so that other vehicles can use the shared information to prevent a potential collision. The advancement of wearable and implantable sensors enables fitness tracker to communicate persons health conditions with PCs and handheld devices. In this section, we focus on the possible integration of intelligent cardiac monitoring system with the V2V-AEB system. By monitoring the drivers heart condition in real time using fitness tracker.

So far as per our study, the research of health-related mobile applications have focused on measuring the pulse rate, blood sugar levels, cholesterol, distance walked/stairs climbed, diet suggestions, calories burnt, etc. [5] [6]. We are concentrating on developing an intelligent system to inform the vehicle in case of a medical emergency such as paralytic attack, cardiac arrest, etc. by studying the frequency of the pulse rate from a fitness tracker. When the vehicle gets the medical emergency information, it broadcasts the message on V2V network, so that other vehicles can try to distance from this vehicle and vehicle can apply a brake to stop safely. Moreover, it can also inform emergency services for getting an immediate medical attention.

2.1 Literature Review

To move forward, it is necessary to study different methods that are available to detect the medical emergency condition. We have also considered various algorithms that are used to study attributes (e.g. pulse rate) from the dataset and detect abnormalities in a patients body. These studies will be discussed in this section.

Analyzing pulse rate dataset is the key part in developing a system. As error in analyzing can excessively temper the results. Different researchers have used different algorithms to analyze the data. Like, Particle Swarm Optimization along with Feed Forward Neural network techniques is used to diagnose heart diseases [14]. Data mining among other algorithms gave 82.5% accuracy in analyzing the data of the patient [15]. Another method researchers use is data mining along with K-mean clustering to cluster the data in groups. Maximal Frequent Itemset Algorithm (MAFIA) is used on these clusters to extract familiar patterns for heart attack [16].

After analyzing the dataset, next step is to identify the anomalies in persons body to detect the emergency medical conditions. There are various algorithms proposed to predict the anomalies of the heartbeat. Cauchy principle Swarm Optimization Algorithm was one of them, which helped the researchers to detect abnormalities in heart rate from the dataset [17]. Whereas, some researchers have also used Bernoulli principle to detect the variation of blood pressure. The blood pressure and the heart rate variability was detected with less than 5% errors by this method [18]

After knowing anomalies in the heart beat the question arises, how can we identify heart attack through it? Various methods have been tried by different researchers. But it has to be considered anomalies in heart rate can be due to many reasons. Heart rate increase could be because of many reasons such as cholesterol, stress, lack of fitness, etc.

Different techniques are used by the researchers to understand the stress levels in a human so as to analyze how the heart rate varies with the activities performed. Wireless body area network is one such system used by the researcher, which is equipped with intelligent sensors to calculate stress levels before performing activities [19].

To predict heart attack researchers have used data mining as one of the techniques. Whereas, some researchers have calculated Heart Rate Variability (HRV) from the ECG and used Support Vector Machine (SCV) classifier to distinguish between healthy and critical patients. Researcher claims it can predict cardiac arrests 30 minutes before the actual attack [20].

Currently, present methods, as per our knowledge use ECG signal to predict medical emergency conditions. But ECG signal can only be measured when a person is at rest or lying down on the bed. Since it is difficult to get the heart rate while driving, we have proposed an algorithm to predict an emergency condition (heart failure) using fitness tracker. We are using decision tree with feedback along with KNN algorithm to anticipate this condition of a user.

2.2 Methodology

Heart rate differs from person to person depending upon various factors such as age, body mass, and fitness level. There are external factors that determine the heart rate too (i.e. atmospheric pressure, altitude, temperature, and humidity). It is a general perception that the regular heart rate of a person is usually in the range of 60-100 beats per minute [21]. There are many situations when the heart beat rate changes abruptly, and a typical situation found regularly is during waking up or sudden body movements. This might cause a heart rate to shoot up for a few seconds. We are attempting to identify heart abnormality by continuously monitoring, analyzing the pulse rate, and body movement of, a vehicle driver using a fitness tracker.

We intend to pass the heart abnormality information to the vehicle to trigger it to brake/pull over automatically and to share the information to the V2V network to alert surrounding vehicles and seek medical assistance.

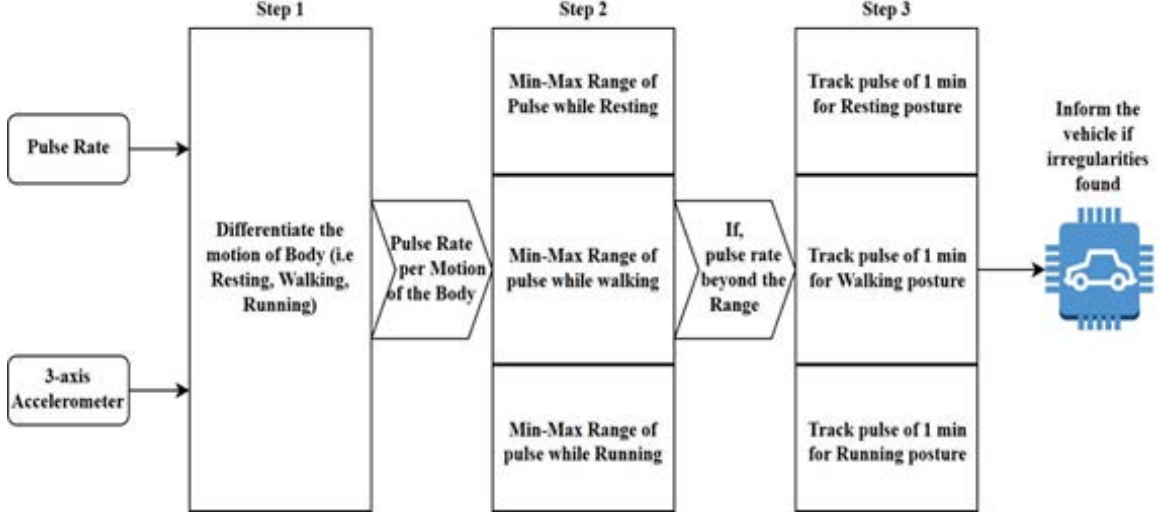


Fig. 2.1. Processing unit of Cardiac monitoring system.

The information used in our proposed system includes heart rate and the tri-axial accelerometer inputs. Additionally, subjects age, BMI, and weight are used to calculate the initial thresholds for the subject. Tri-axial acceleration sensor data is used to determine the motion that the user is performing [22]. While other attributes such as pulse rate, BMI, age, and medical history are used to predict the emergency condition. If an abnormal pulse rate is detected, then the system will output this information.

The data is processed in a three-step approach:

- (1) Get a prerecorded heart rate dataset of many human subjects. Analyze the dataset to extract the signal patterns of normal and abnormal heart rate based on some attributes.

(2) Gather real-time heartbeat rate information from vehicle drivers. Identify the abnormal signal patterns learned from step (1).

(3) Create a warning signal to the vehicle for automatic emergency braking/pull over, warn nearby vehicles for abnormal driving behavior through a V2V network, and request for medical help through a V2V network.

2.3 Analyze the Pre-recorded Dataset

27 individuals heart beat history was used to test the proposed method. These datasets were taken from the UCI (University of California, Irvine) Machine learning repository and Eric (Entrepts, Representation et Ingénierie des Connaissances) laboratory repository [23] [24] [25]. Within these 27 individuals, the data set of 9 healthy individuals (8 males and 1 female aged 27.223.31 years and BMI 25.112.62 $\frac{kg}{m^2}$) has the information about the acceleration sensor and pulse rate for 18 different physical activities performed in 10 hrs. This data is collected using a heart rate monitor and inertial sensors. Out of 9 healthy individuals data, 5 were used to extract the attributes and 4 were used to test the proposed method. The data set of the other 18 people has the information about their heart pulse rate of a patient in at rest position for 24 hours. The datasets of 8 out of these 18 patients were used to extract features and 10 were used to test the proposed method.

In data from 9 healthy people, each subjects activity consists of heart rate records obtained from fitness tracker and the 3D accelerometer with respect to time. The 3D accelerometer data can be analyzed to calculate the velocity and displacement from the statistical estimate of accelerations along the x, y, and z-axis. The data set has the data from 2-accelerometer sensors, one with 6G maximum acceleration and the other with 16G maximum acceleration.

During high-intensity movement, a person's high impact may saturate the 6G accelerometer, so the data from the 16G accelerometer should be used. The sampling rate of the heartbeat rate monitor is 9Hz, and the sampling rate of the accelerometer is 100Hertz. Additionally, subjects' age, BMI, and weight are available. The data set has the information about pulse rate after every 1-minute interval.

To extract the abnormal heart beat pattern, we analyze the data in three steps (as shown in Fig 2.1.):

Step 1: Bifurcate the pulse rate according to users motion type, as we know that the pulse rate varies according to the motion types.

Step 2: Determine the normal/abnormal pulse rate range for each body motion type.

Step 3: Verify if the heart beat shoot up was due to some external factor or health condition by studying the unusual frequency of the pulse rate.

2.3.1 Bifurcate the pulse rates of a particular user according to motion types.

Different physical activities of subjects are classified into three main levels: resting (sitting, lying, etc.), walking, and running (playing soccer, running, etc.). The dataset has activity IDs to indicate subjects motion type that makes it easier to organize the data and bifurcate.

Preprocess the data:

Some part of the data is questionable, as indicated by the data set. Thus, only the correct sections of the data set are selected. KNN (K-nearest neighbors) classification is used on accelerometer data to differentiate body movements into activity levels. KNN is a supervised learning algorithm where the result is classified based on the majority of K-Nearest Neighbor category. KNN is also called a lazy learning algorithm because it is a type of instance-based learning algorithm.

Before using the KNN algorithm on the acceleration sensor from dataset, it is necessary to study the behavior of acceleration sensor data for different activities. Figure 2.2 represents the probability function for the relative acceleration data used of different physical activities (Resting, Walking, and Running). The x-axis is relative acceleration sensor data and the y-axis is probability function, which estimates the probability of a single sample data having an instantaneous value greater than the probability value. The Purple line is for resting, the Green line is for walking, and the Black line is for running. For lower acceleration values, the probability function has greater values with respect to resting posture, whereas for higher acceleration values, the probability function curve for running data points is present only. From the graph, it can be depicted that an increase in the motion of a body is directly proportional to the value of acceleration sensor data.

i.e.

$$A_{re} < A_w < A_r$$

Where,

A_{re} = Acceleration sensor value while resting

A_w = Acceleration sensor value while walking

A_r = Acceleration sensor value while running

When the KNN algorithm is used to predict the motion of a user, the input of a acceleration sensor is compared with the training dataset extracted from 5 users. In the KNN algorithm, from the training dataset K-nearest neighbors are searched, and it classifies input into groups (i.e. resting, walking, running) who have a maximum number of votes in the defined (K) neighborhood.

Example: let us consider KNN classifier with $k=3$. The below example shows that there are two groups in which the input should be classified. The red cross and blue dots represent two classifications from the training dataset. When an input is given as shown by the white dot, it checks the K nearest neighbor. Here, K is equal to 3, and the nearest neighbor is shown in the dotted circle. The point is classified into a group which has the maximum member in the defined neighborhood of the input.

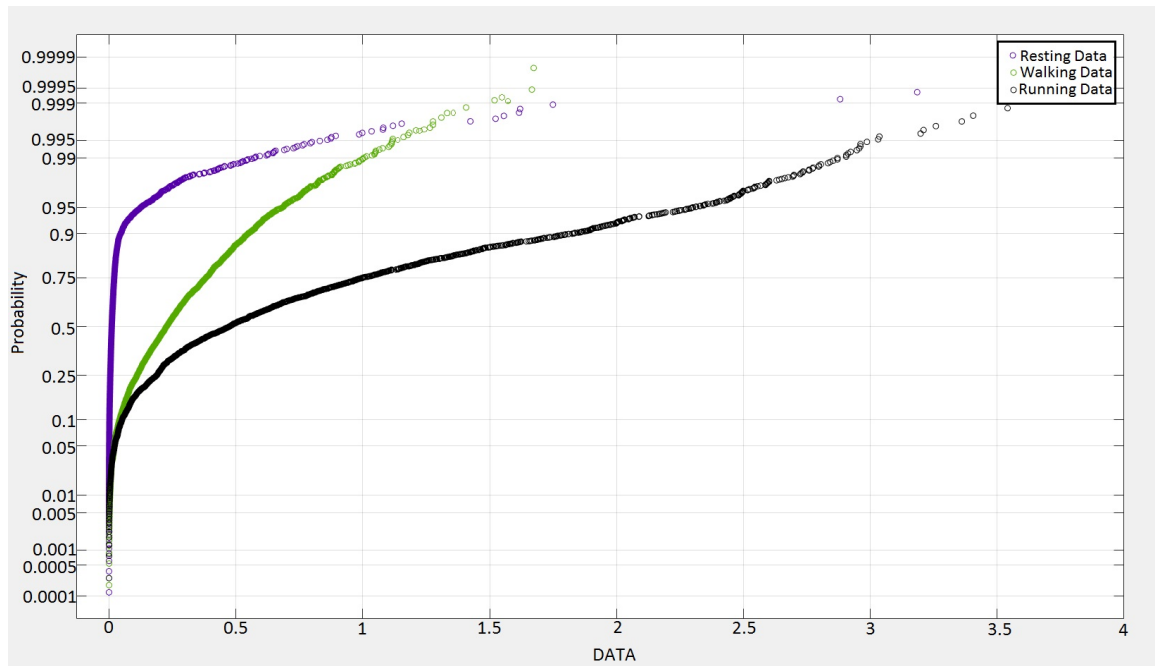


Fig. 2.2. Acceleration sensor data

Here when we check the 3 nearest neighbors of the input, the weight of the group represented by the red cross is 2 and represented by the blue dot is 1. Thus the input belongs to group 1, which is represented by the red cross.

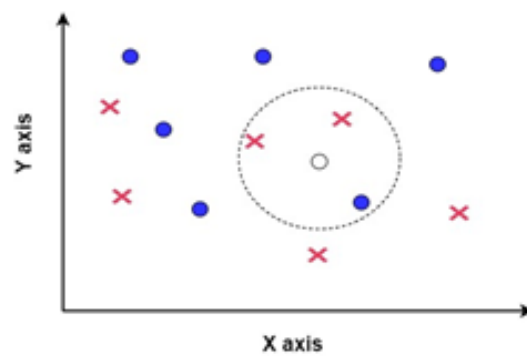


Fig. 2.3. A KNN algorithm example

Probabilistic interpretation:

Let,

$$\text{training set } T = \{(x_1, y_1), \dots, (x_n, y_n)\}$$

Where,

x_i are the points in training dataset, $x_i \in R^d$,

y_i is classification in finite set, let $y_i \in \{0, 1\}$

Let x be a new input that we want to classify in which group they lie (i.e. what is y corresponding to x)

Let K be a fixed variable

Let us define random variable $Y \sim P$

$$P(y | x, T) = P(y) = \text{fraction of points } x_i \text{ in } N_k(x) \text{ st } y_i = y$$

$N_k(x)$ = k nearest points to x

$$\text{Prediction of classification, } \hat{y} = \arg \max_y P(y|x, T)$$

We have seen how the KNN algorithm works, to use the KNN classifier to classify the acceleration data it's necessary to extract correct data points from the training data set. To extract the attributes for the algorithm, first, we remove the questionable data from data set. The dubious data is mentioned in the data set in which data is questionable. Then the data from the training set is classified in 3 activities (resting, walking, running) as mentioned earlier. The classification of the training dataset is done by using activity IDs provided in the data set. Then this dataset is used to classify the input acceleration sensor value.

The next point arises, which is how to find the best K value to get maximum accuracy, i.e. how many nearest neighbors should be taken into consideration to classify the input. To find the value of K , we used the 2 fold cross validation method. The training data is divided into two groups, one of the two groups is used as the training set and the other as the testing set alternatively to find K .

To find the distance from each data in the training set, the classification algorithm will take $O(nd)$ time. Where d is time to calculate distance and n is the total number of data points in the training set. The accelerometer gives the data in 3 axes, it will consume a lot of time to find the distance from each data point. To reduce the time (i.e., to reduce d) we find the relative acceleration (eq 2.1) so that single value can represent all 3-axes' values and the value of d can be reduced. Then the acceleration data set is normalized in the range of 0 to 1 using eq (2.2)

$$A = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad (2.1)$$

Where,

A = resultant acceleration

a_x = acceleration in x direction

a_y = acceleration in y direction

a_z = acceleration in z direction

$$NA_i = \frac{A_i - \min(A)}{\max(A) - \min(A)} \quad (2.2)$$

Where,

NA = normalized value of acceleration

A = resultant acceleration

$\min(A)$ = minimum value of resultant acceleration for each activity

$\max(A)$ = maximum value of resultant acceleration for each activity

The result of normalization for relative acceleration is shown in Fig. 2.4. The figure below has time on its x-axis and resultant acceleration (A) data on the y-axis. The green peaks show the relative acceleration sensor data whereas the blue peaks show normalized acceleration sensor data.

The normalization of data is done for classification. The classification result of acceleration data using KNN is shown in Fig. 2.5. The green box indicates the accuracy of detection in the correct particular type of motion, whereas red indicates

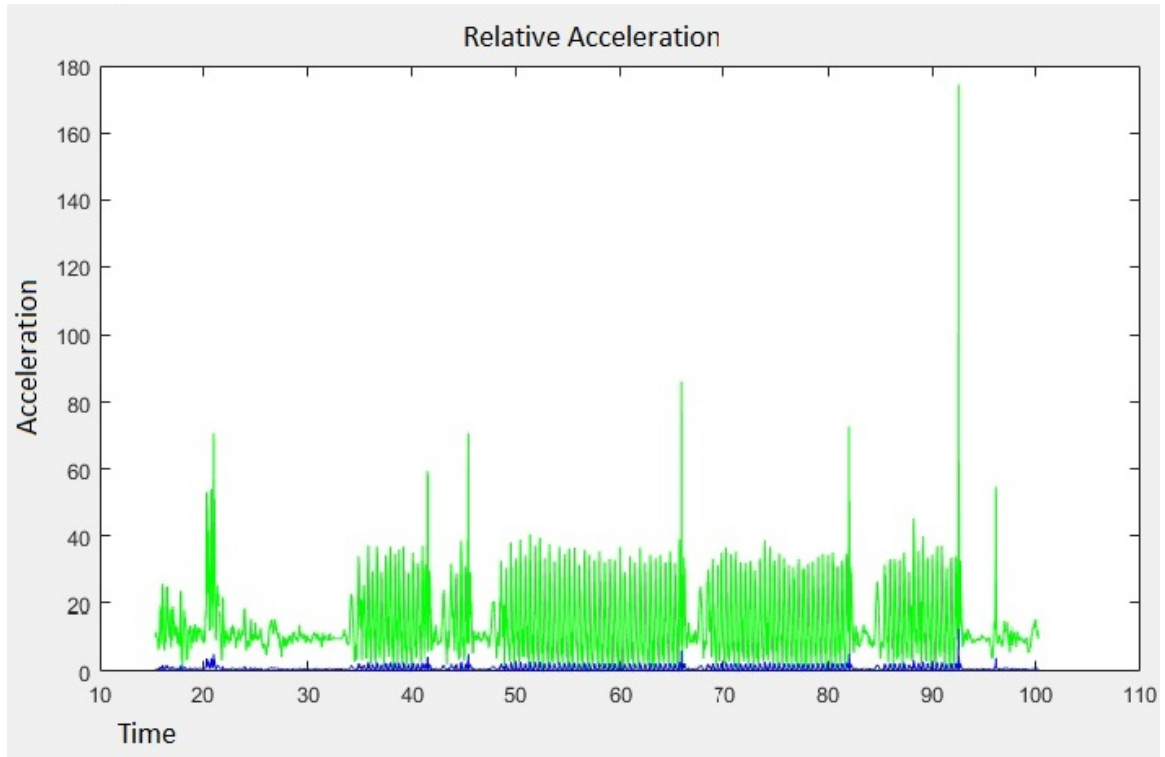


Fig. 2.4. Normalization of relative acceleration

the error (i.e. the detection of particular data in the wrong state of motion). It shows that overall accuracy for the detection of data into its own respective category is 87.1%.

The KNN algorithm finds the distance from all the data in the training set and then it compares the K-nearest neighbor to classify the input. Thus its time complexity to sort is $O(nd+n\log(k))$. If $O(d)$ is the time to calculate the distance, its time complexity becomes $O(nd)$, where n is a total number of elements in the training dataset. This is because the distance is calculated for each data point present in the training set. While choosing the k smallest distance from the n dataset it will take $O(n\log(k))$ time. This process is time-consuming due to the large data set available.

To reduce the time complexity and the space complexity, we have used the relative acceleration data for analysis. This acceleration data covers all the motion types (i.e.



Fig. 2.5. Classification using the KNN algorithm from relative acceleration

resting, walking and running), so they are divided into three categories with respect to an activity ID given in the dataset. The window of time w is chosen, and the variation of relative acceleration is found on the initial and end of the window. The mean and standard deviation of each group is calculated which is further used to classify the activity using acceleration sensor data.

$$VA_m = \frac{\sum_{i=1}^n VA_i}{N} \quad (2.3)$$

Where,

VA_m = mean of Variation in Acceleration for specific activity

VA = Variation in relative acceleration for specific activity

N = Total number of data

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (V A_i - V A_m)^2} \quad (2.4)$$

Where,

σ = standard deviation

The mean (eq. 2.3) and the 2nd standard deviation (eq. 2.4) of each motion type are calculated. They are used to classify the acceleration sensor data. The 2nd standard deviation of each group is calculated, as it states the range of 95.4% of the data from data set. Thus, it can be used to check whether the input lies in this range or not. The 2nd standard deviation value is chosen to prevent overlapping in the classification of acceleration data. These features are used to classify input in respective categories. To classify the input, the normalized value of the relative acceleration is calculated and compared with 2nd deviation value of 3 groups. Thus, the time complexity is $O(c)$ time. Where c is a constant time to calculate relative acceleration and normalization of the input value and comparing with the value of standard deviation of 3 groups.

The overall accuracy of the method is 78%, which is less than KNN classifier. However, the efficiency of the classifier can be afforded as the heart rate is monitored in 2 more steps and our goal is to detect an emergency condition in which time plays an important role.

2.3.2 Find normal and abnormal heart beat patterns

The bifurcated pulse rate from activity classification in step 1 is passed to step 2 to detect abnormal heartbeat patterns, considering the activity classification from step 1. But to identify the abnormal heartbeat patterns, it is important to study the nature of pulse rate. The pulse rate is highly dependent on factors like age, sex, and BMI. According to [26], the safe maximum and safe minimum pulse rate of people of different age groups are shown in Table 2.1.

Table 2.1.
Table for average heart rates [26]

Newborns	1-30 days old	70-190
Infants	1-11 months	80-160
Toddlers	1-2 years old	80-130
Preschoolers	3-4 years old	80-120
Elementary Age	5-10 years	70-115
Teenagers	10-20 years	60-100
Adults	20-60 years	60-100

Psychological effects of stress can also contribute to heart rate increase while performing activities such as yoga or meditation could bring the heart rate back to normal. Typically, athletes have a resting heart rate as low as 50-60 beats per minute. The maximum heart rate that can be achieved by individuals is given by the formula: $220 - (\text{age})$ [27]. According to reports [8], the heart rate for a healthy person while exercising is between 50% of $(220 - \text{age})$ and 85% of $(220 - \text{age})$ [28] [29] [30]. As per studies conducted by Cleveland Clinic, it is to be noted that if a persons heart rate is above 220 for more than a minute, it may lead to heart muscle damage resulting in arrhythmia [31] [32].

$$\text{Maximumheartrate} = 220 - (\text{age}) \quad (2.5)$$

$$\text{Minimumheartratedurinexcercise} = 0.5(220 - (\text{age})) \quad (2.6)$$

$$\text{Maximumheartrateduringexcercise} = 0.85(220 - (\text{age})) \quad (2.7)$$

$$\text{Maximumheartrate} < 220 \quad (2.8)$$

As heart rate depends on various factors, it is necessary to personalize the algorithm as per the user. To customize the system is calculates a maximum and minimum pulse rates for each subject. Initially, we do not have the average pulse

rates of the subject. Hence, we will instead ask the subject to input some of the information like age, height, BMI, etc., and use Table 1 and equations (2.5-2.8) to assign initial safe minimum and safe maximum. Once the data starts coming to the system, the program calculates the minimum and maximum range of pulse rate as per the user. Thus, its accuracy in detection of an emergency condition will improve with time. It calculates the mean pulse rate of a subject using eq (2.9).

$$NewMean = \frac{MeanNo + 24_mean}{No + 1} \quad (2.9)$$

Where,

Mean=previous Mean pulse rate

No=Number of previous days used for calculating new mean pulse rate.

24_mean=mean of the user pulse rate within 24 hours

The safe minimum and the maximum values of the subject are calculated using equations (2.10) and (2.11).

$$Safe\ minimum = \frac{Previous\ minimum\ pulse\ rate + Minimum\ Pulse\ rate}{2} \quad (2.10)$$

$$Safe\ maximum = \frac{Previous\ maximum\ pulse\ rate + Maximum\ Pulse\ rate}{2} \quad (2.11)$$

Where,

Minimum Pulse Rate=Minimum pulse rate value in particular activity.

Maximum Pulse Rate=Maximum pulse rate value in particular activity.

The abnormally low and high pulse rates can be identified based on equations (2.12) and (2.13), respectively

$$Low\ pulse\ rate : Pulserate < safe\ minimum \quad (2.12)$$

$$High\ pulse\ rate : Pulserate > safe\ maximum \quad (2.13)$$

The pulse rate fluctuations might be due to various reasons. Also, there might be the wrong classification from step1; this may lead to a false alarm. To avoid such situation, we further investigate the health condition to understand how drastically the pulse rate has changed.

2.3.3 Verification of abnormal heart rate

Step 2 indicates if the pulse rate goes beyond the expected safe ranges. Step 3 examines the indication closely based on other factors such as frequency variation in the last three pulse rates. The trigger through step 2 can be due to various reasons like: due to external factors (temperature of the environment), a sudden change in activity, and other health conditions or due to the wrong classification of activity. For example, if a person is doing exercise his pulse rate goes high. After completion of exercise when a person sits to relax, his heart rate would still be high under normal condition. However, the system may detect it as an emergency from step 2, but it is not an emergency condition and can be verified by studying previous pulse rate. Also, there are various other reasons like stress, which might lead to increase in pulse rate [33]. However, stress is steady process thus pulse rate will also increase gradually. Moreover, other external factors (temperature of the environment), excitement also lead to gradual increase in pulse rate.

Whereas, the attack is a sudden phenomenon, which requires immediate medical attention. Thus during medical emergency condition like heart attack, pulse rate changes drastically over a short period [34] [33]. Thus, emergency conditions can be verified by checking whether there was a drastic change in pulse rate or it is gradual. To check this, we monitor the fluctuations in the heart rate closely for a certain set period (in this case, we observe the fluctuation closely for 3-4 minute). In order to check the drastic change of pulse rate so that attack can be verified. To calculate drastic change inequalities (2.14) and (2.15) are checked.

$$|P_c - P_{c-1}| > \frac{|SafeMax - SafeMin|}{2} \quad (2.14)$$

Where,

(P_c) refers to the current Pulse rate

(P_{c-1}) refers to previous Pulse rate

$$|P_{c-1} - P_{c-2}| > \frac{|SafeMax - SafeMin|}{2} \quad (2.15)$$

Where,

(P_{c-1}) refers to previous Pulse rate

(P_{c-2}) refers to 2nd previous Pulse rate

If the heart rate change is less than the maximum change rate and is not satisfying either inequality (2.14) or inequality (2.15), it stores the value of pulse rate in a separate matrix (matrix [A]), to analyze the reason for the sudden fluctuations in pulse rate. However, if both inequality 2.14 and 2.15 are satisfied, it triggers the vehicle and sends the information to the health care centers to take a quick action.

Table 2.2.
Matrix A: to study the abnormality in heart rate

Time	P_c	P_{c-1}	P_{c-2}
T1	X1	X2	X3
T2	X4	X5	X6
T3	X7	X8	X9
T4	X10	X11	X12

From matrix [A], where we have stored irregular pulse rates, we can study them to know the cause of the situation. We can also study the altitude and acceleration sensor data to understand if the user was at a higher altitude or if s/he was doing some sort of physical activity that led to the unusual pulse rate. However, if this is not the case, we can see whether this situation has occurred previously or not and then retrieve the data to analyze if there is any particular pattern to it. Moreover,

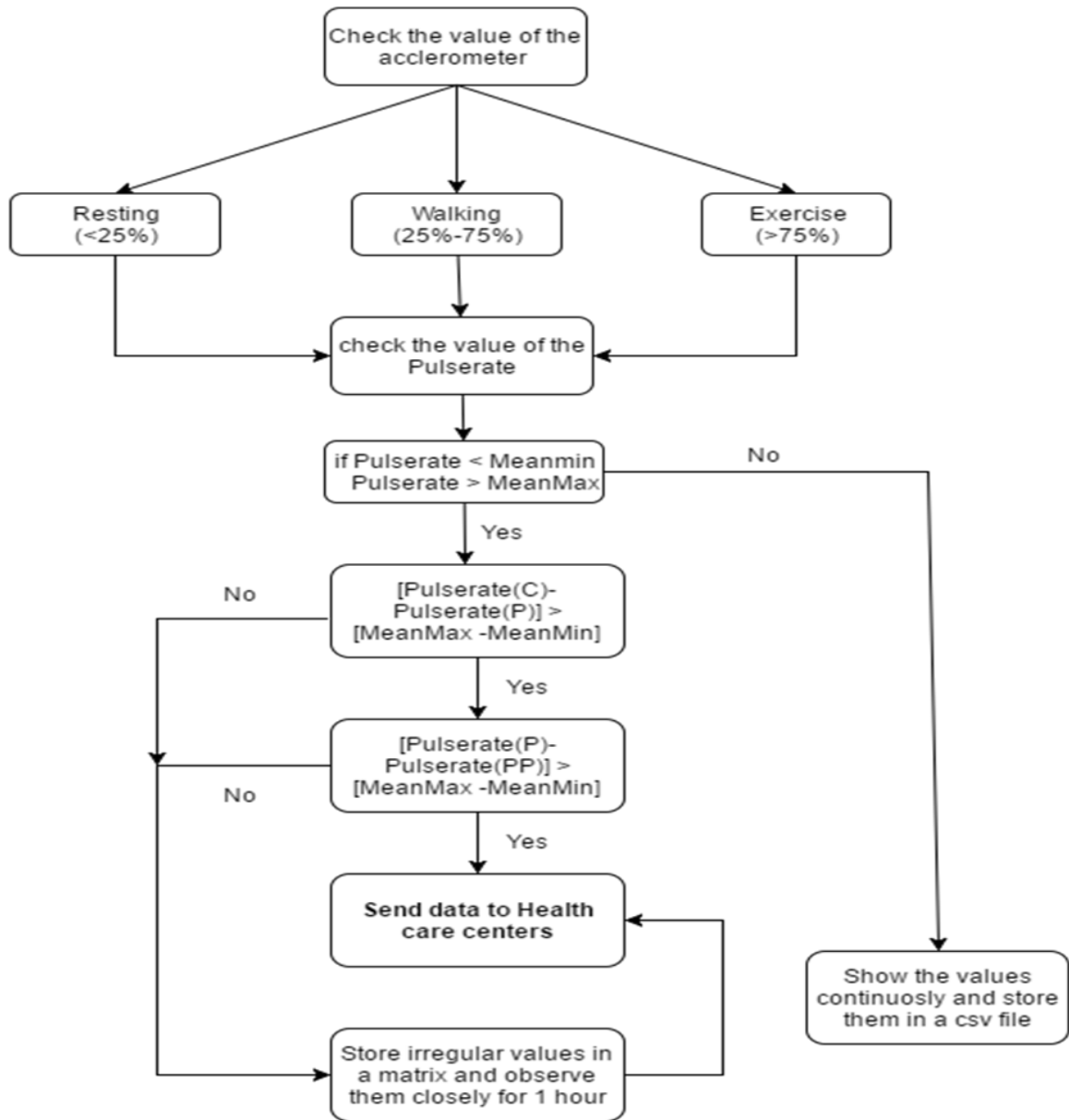


Fig. 2.6. Detailed system diagram

if it happens often, we can send the report of the pulse rate for 24 hours to a doctor and request a patient body checkup, as well.

The proposed method is tested on ten patient data and four healthy persons. For activity classification and attributes extraction (minimum, maximum, safe minimum,

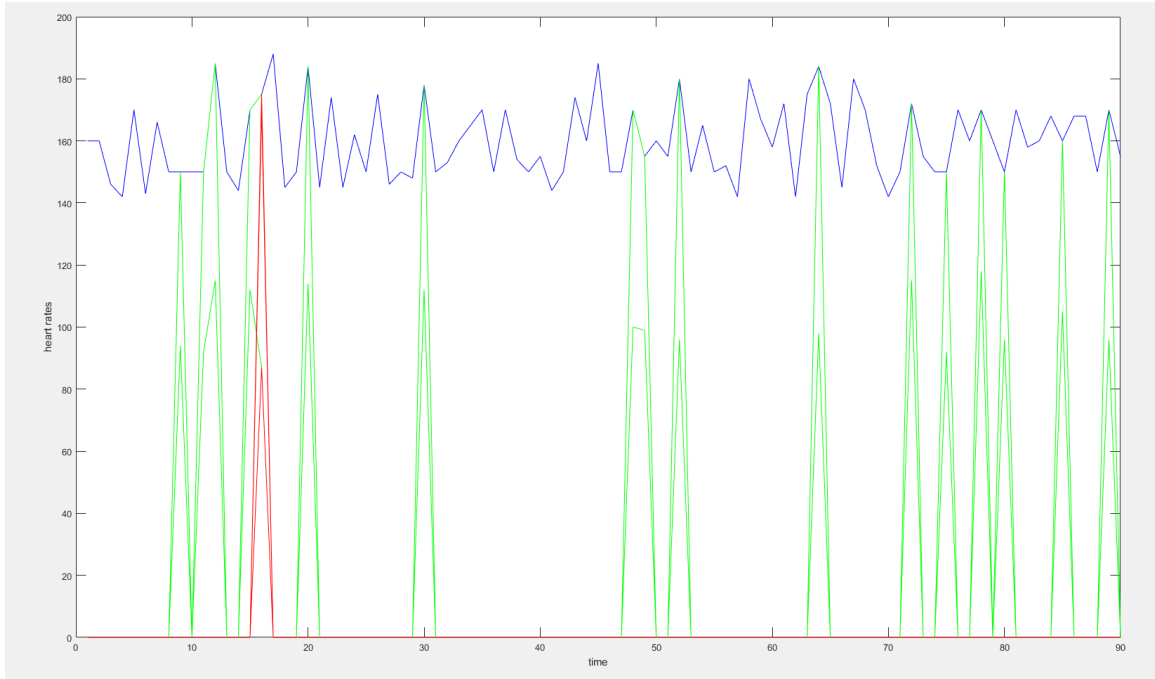


Fig. 2.7. Heart attack detection

safe maximum and mean value of pulse rate), we used five healthy persons data and eight heart patients data. Here is one of the visual analysis of the saved file with data from a patient of 32 years old with 64 Kg (Fig5). His resting heart rate was 120, and maximum heart rate was 185. The data is from ECG during the period when a patient got a heart attack.

When the pulse rate of the subject is below safe minimum pulse rate or above safe maximum pulse rate, the data was saved and represented in the graph by blue curve in Fig. 2.7. If the pulse rate was not in the safe range (i.e. if it is above safe maximum or below safe minimum), the data was compared to the previous pulse rate and if it satisfies inequality 2.14 as mentioned earlier those data is also saved separately, the green curve in Fig. 2.7 represents it. The two peaks show that previous two-pulse rate changes that are compared and were found to be out of normal range. If the pulse rate is changed drastically as per inequalities 2.14 and 2.15, the information

should be sent to the vehicle for automatic emergency braking and broadcast in V2V network for seeking help and warning nearby vehicles. The red peak in Figure 5 shows the point when the emergency heart condition information is sent.

2.4 Adapting Intelligent Cardiac Monitoring system in V2V-AEB

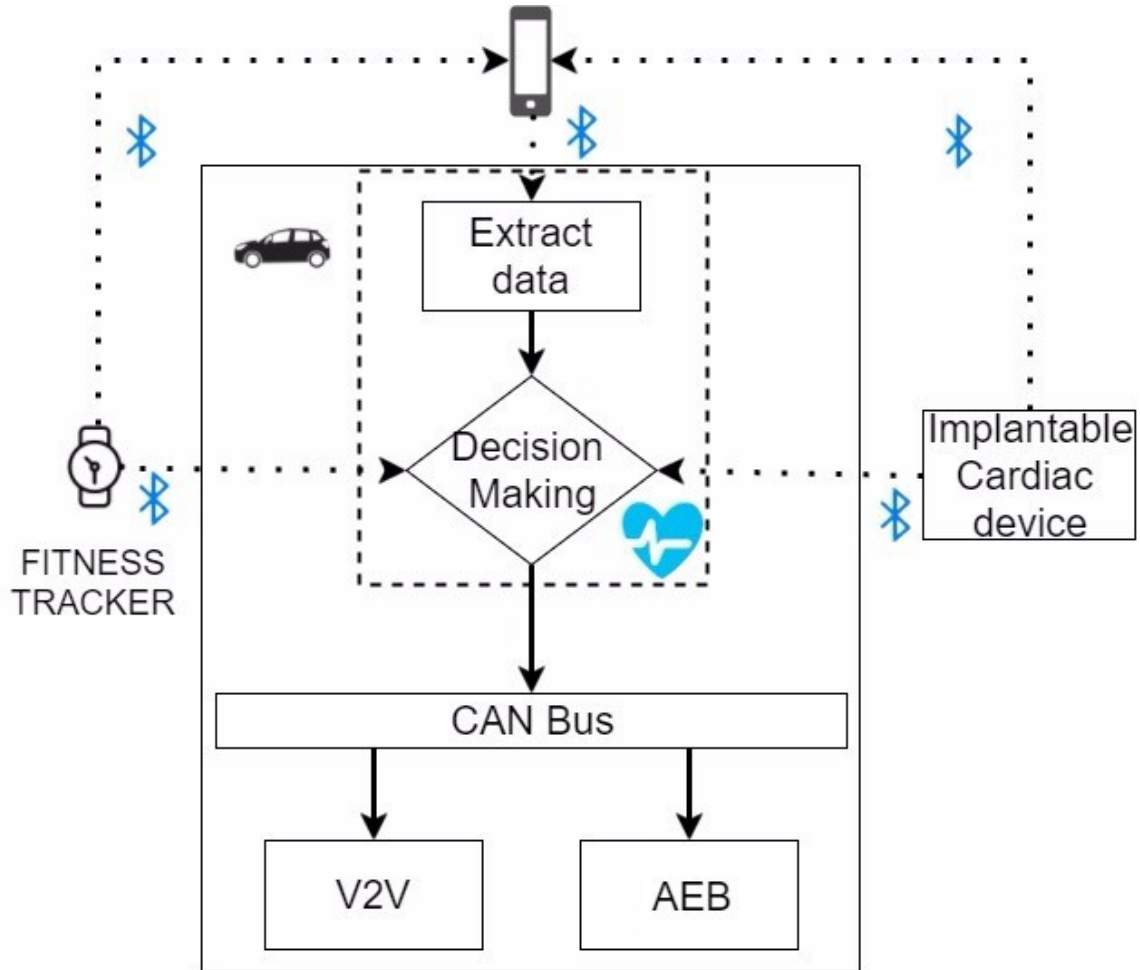


Fig. 2.8. Integration of V2V-AEB and Intelligent cardiac monitoring system

We have looked into the advantages of V2V-AEB system, to make driving safer we proposed a method to integrate the intelligent health monitoring system with V2V-AEB. Various problems need to be solved to integrate the system. Importing pulse

rate to a vehicle is one of them, pulse rate from devices such as fitness tracker or Implantable Cardiac device, can be imported through Bluetooth. As fitness tracker and Implantable cardiac device calculate the pulse rate in real time, this information tracked by the device can be used to monitor the health condition of the driver. However, the other question arises is how to import the drivers data such as his age, sex, Maximum pulse rate, Minimum pulse rate; because it is not necessary that a vehicle is used by just one driver only. To extract these attributes vehicle can connect with the mobile phone of the driver as unlike vehicle, mobile phone nowadays is personalized. Thus, a vehicle can import the drivers data such as his maximum pulse rate, minimum pulse rate, etc. After extracting the data from a mobile phone, the pulse rate could be monitored by vehicle through fitness tracker or Implantable Cardiac device. When the health monitoring system detects an emergency in the vehicle, a triggered signal should be generated to activate V2V-AEB system of a vehicle. To generate the triggered signal the vehicle can use CAN bus. The CAN bus connects the V2V and AEB system of the vehicle. The triggered signal can activate the V2V-AEB system as proposed to take desired decision.

When the system triggers the vehicle under an emergency condition, it executes the Automatic Emergency Braking (AEB) protocol. AEB helps the driver to stop the vehicle at a safe position. So that there is no accident, in a case when the driver is unconscious during medical emergency condition he does not need to panic for the control of the vehicle. Otherwise, this can make drivers health condition worse. Simultaneously, vehicle broadcast emergency message in V2V network so that other vehicle can come to know about the emergency condition and immediate medical attention can be provided to the driver. Also, it can prevent collision with other cars, as other vehicles would be aware of the patients vehicle and they can try to assist the patient.

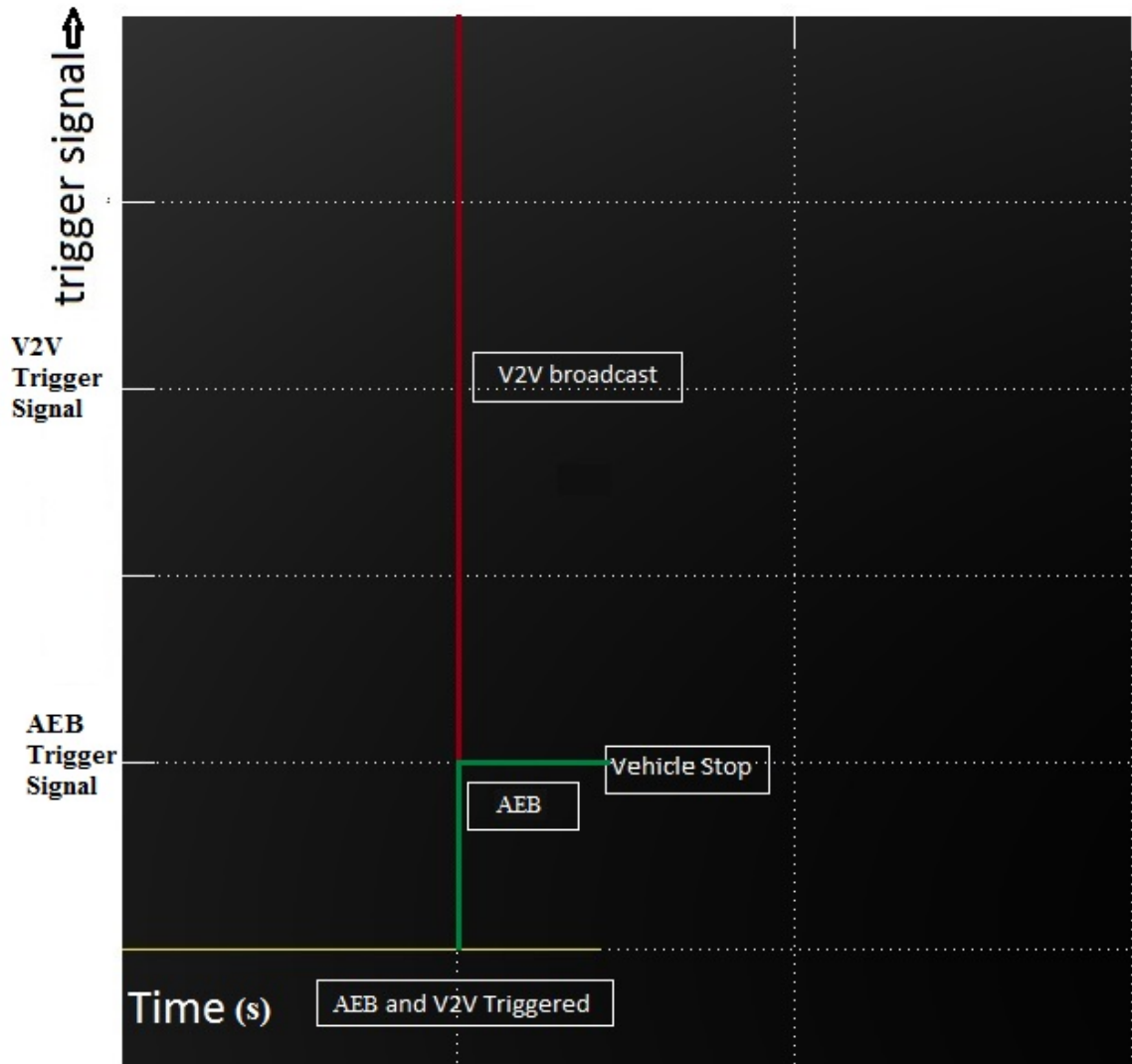


Fig. 2.9. Implementation process of Cardiac Monitoring System(Trigger signal-Time)

2.4.1 Simulation

Simulation by PreScan software is used to demonstrate the proposed method. The pulse rate of a heart patient at rest condition in the dataset is fed as an input, assuming heart patient is driving the vehicle. When driver had a heart attack, the system triggered the vehicle for stopping. The timing of the execution is shown in

Fig. 2.9. The AEB system was activated along with the V2V system. The vehicle stopped at a safe location and broadcasted its location in V2V network. The x-axis is the time whereas the y-axis is the trigger signal. It represents when the system triggers the vehicles AEB system and V2V system and when the vehicle stops.

2.4.2 Hardware Model

The proposed method has also been implemented and tested using FRDM K64 and finger heart rate sensor. After getting the pulse rate value, the information is sent to the cloud using AT&T M2X. M2X is an IOT platform provided by AT&T, we have used it to store the real-time processed data and for triggering in the case of emergency. Let us first study about finger heart rate sensor.

Heart Rate Sensor Module:

The module (as shown in Fig. 2.10) uses photo transistor and infrared led (IR) to detect the pulse of the finger. Red led flashes whenever a pulse is detected. There is a led on the light side of the finger and a phototransistor on the other side of the finger, which is used to obtain flux emitted. The resistance of the photoresistor will vary as pulse will change. The heart beat sensor module has three pins: Signal (Analog signal), 5V and ground.

FRDM K64:

FRDM K64 is a low power (250A/MHz) Freescale development platform. It has 120 MHz ARM cortex-M4 core microcontroller with 1 MB flash memory and 256 kb RAM. The board includes 6-axis digital accelerometer and magnetometer which is required to detect the motion of the user. This feature of FRDM K64 makes as an ideal selection for our system. The pin configuration of FRDM K64 and connection with Heartbeat Sensor is shown below in Fig. 2.11

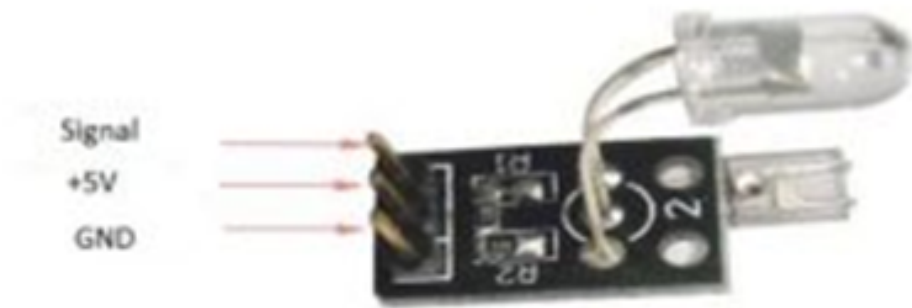


Fig. 2.10. Heart rate sensor module

Working:

The FRDM K64 operates on the mbed program; the proposed system is programmed using Embedded C. Onboard acceleration sensor is used to predict the motion of the body. As per the motion of a body, the pulse rate has been processed as explained earlier. This setup was tested on five people with age group 24-34. The Fig. 2.11 shows the heart rate of one of the user.

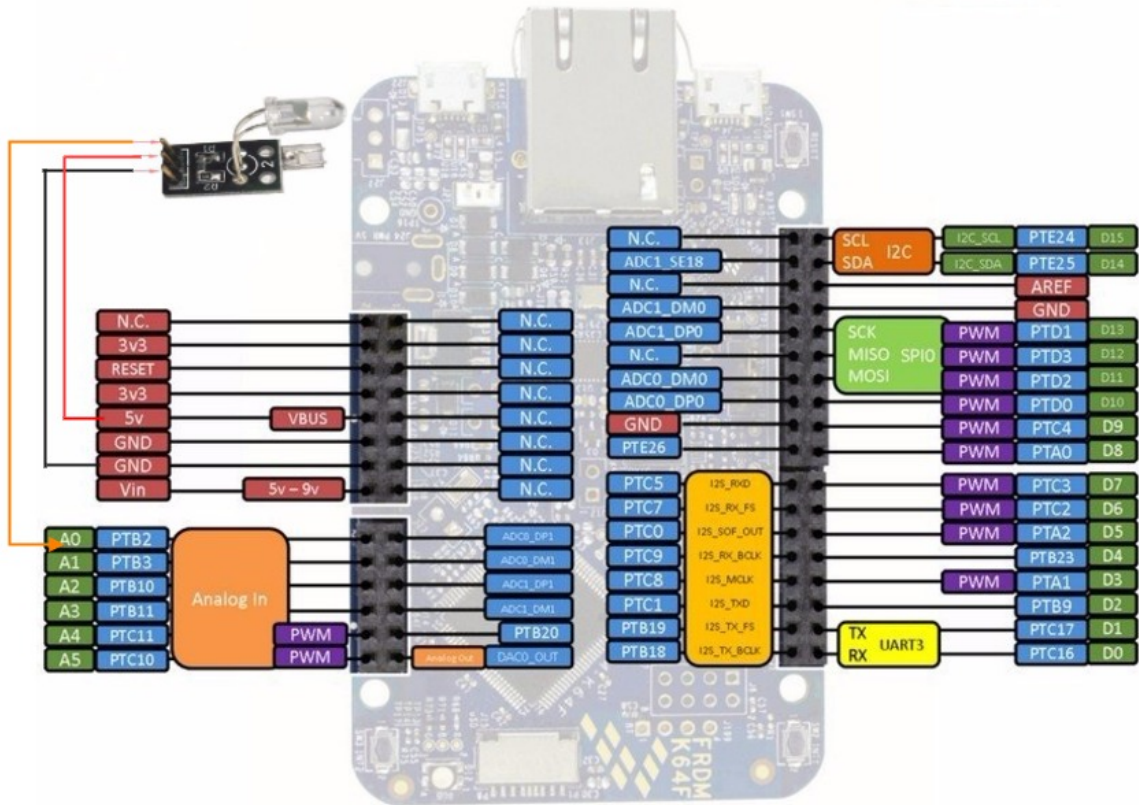


Fig. 2.11. Connection of heart rate sensor module with FRDM K-64



Fig. 2.12. Real time pulse rate using FRDM K64

3. EFFECT OF DELAY IN V2V-AEB

We have read about the proposed system in previous sections. There can be various constraints like delay in the system while implementing the proposed system. This delay might reduce the effectiveness of the proposed system. It is necessary to control delay for an efficient V2V-AEB system. As delay will result in a late response by the AEB system, which may lead to a collision. For the system to function properly, the time delay in the system should not exceed a certain limit. If the delay is too long, the receiving vehicle may not have time to respond to the information, hence the shared AEB information will become useless, and to make V2V-AEB system more effective, the delays need to be resolved.

To make system robust such that delay in the system does not reduce its effectiveness while making the decision, it is necessary to study the effect of delay thoroughly and to handle them properly [13]. One common practice to handle the delayed trajectory information is to extrapolate trajectory to the current time. We have put forward a dynamic system that helps to reduce the effect of delay in different environments without extrapolating trajectory of the pedestrian. In V2V-AEB system, various time delays can occur at each information processing step, starting from detecting pedestrians through onboard sensors, converting them into message format (D_s), sending the information about those pedestrian to other vehicles (D_c), processing all the received information on receiver side, merging those information with self AEB system and using those data to make appropriate decision (D_p). Based on the path of information flow we have divided all these delays into four parts. The total delay (D) in the system is the sum of all delay parts.

$$D = D_s + D_c + D_p + D_m \quad (3.1)$$

Where,

Table 3.1.
Bifurcation of delay (D)

D_s	Sender delay
D_c	Signal transmission delay (Communication delay)
D_p	Signal Processing delay
D_m	Mechanical delay

To develop algorithms for handling the delay in the real system, it is necessary to study the delays given by equation 3.1 and reason for these delays in the system.

Sender delay (D_s):

Vehicles detect the objects using its onboard AEB sensors such as radar, LIDAR, and camera. Then it determines if the detected object is a pedestrian or a vehicle and finds its speed, location, and moving direction. Later this information is converted into message format to broadcast over V2V network [11]. All these processing steps take some time causing a certain time delay. This delay will increase as the number of pedestrian increases. Since, it will take the time to track each pedestrian, differentiate various information, and convert all the information into the message format.

Communication delay (D_c):

A communication delay in the V2V communication can also be termed as an end to end delay. End to end delay refers to the time taken for a packet to be transmitted across a network from source to destination. The message size and the network load

affect it. For example, if there are m cars and n pedestrian there will be in total $m*n$ messages in the system so it will require some time for a car to process the messages. This time delay is known as communication delay. The communication delay may also occur due to packet collision. Packet collision occur if there are more than one packet in the system and it is directly proportional to number of messages.

Delay on receiver side (D_p):

Signal processing delay includes delay during message decoding, AEB information merging; command to actual braking as shown below:

a. Message preprocessing

As there may be many messages received from V2V network simultaneously [35], the message queuing and decoding may cause some delay. Thus it can be said that delay due to message merging is directly proportional to the number of messages received by the vehicle.

b. Message merge

There may be many senders in V2V-AEB system. Each vehicle may provide different information for the same object [35]. Merging all information provided by different senders causes certain delay.

c. Tracking

Abruptly change in the position of the pedestrian or too many objects in the system may confuse the system [35] which can cause the delay while tracking. For example, if the pedestrian got panic and changes its motion suddenly, the system will require some time to follow the pedestrian, this will lead to a delay in the system.

d. Pedestrian information merge

While merging the information provided by its AEB system and other vehicles in V2V network [35] there can be some delay. As both the information can be different and it will require some time to merge those pieces of information.

Mechanical delay (D_m):

While communicating the decision to the braking system to stop the vehicle, there can be a delay. Also, weather condition may lead to decrease in braking efficiency i.e. more time for stopping the vehicle. For example, if it is raining or there is snow the friction between tires of the car and road will be less, which will lead to delay in stopping the car. Assuming proper operation of the brake the minimum stopping distance for an automobile is determined by the coefficient of friction between road and tires. The kinetic energy of the car is required to reduce to zero by friction force. If the wheels of the vehicle continue to turn while braking, the static friction is operating, while the wheels are locked and sliding over the road surface, the braking force is a kinetic friction force.

Kinetic energy to zero,

$$\text{Work by friction} = -\mu mgd = -\frac{1}{2}mv_0^2 \quad (3.2)$$

$$\text{Stopping distance, } d = \frac{v_0^2}{2\mu g} \quad (3.3)$$

The stopping distance is inversely proportional to friction coefficient. So as the friction decreases the stopping distance increases. So the vehicle should start applying in advance to stop at a particular point.

3.1 Mathematical Model to Reduce Effect of Delay

We have seen the reasons which may lead to delay in the system. Now we will try to find mathematically, how can we overcome the delay in the system? Before going forward, we define certain timing terms. Each vehicle model has its property; they have different minimum time for breaking, i.e., time to stop for any particular condition. All timing is in reference to potential collision location.

Time to collision (ttc): ttc is the instantaneous ratio of the distance to the potential crash location to current vehicle velocity.

Time threshold for braking (ttb): Is the minimum time that the vehicle needs with maximum braking to stop at a potential crash location in an idle condition.

Time to start braking: (tsb): Is the time from when the vehicle starts breaking to vehicle stops at the potential crash location.

Fig. 2 explains ttb, tsb and ttc. When $ttc = ttb$, the vehicle needs to brake with full power to avoid a collision. When $ttc < ttb$, the collision cannot be avoided. The vehicle can only control tsb for avoiding a collision. For collision avoidance, following condition must be satisfied

$$ttc \geq tsb \geq ttb \quad (3.4)$$

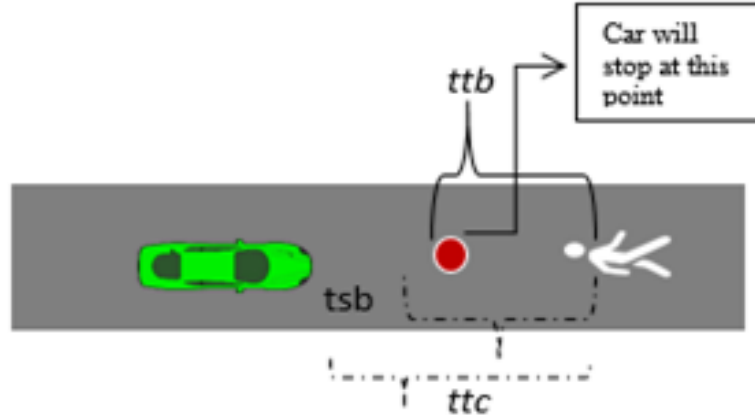


Fig. 3.1. Vehicle's ttb, tsb and ttc

To understand the effect of delay, let us consider the scenario as shown in Fig. 3.3. $C1$, $C2$, and $C3$ represent car 1, 2 and 3 respectively. $T1$ represents the truck and P represents the pedestrian. All vehicles are V2V-AEB enabled. This scenario shows how the V2V-AEB system works and how delay may affect the proposed system.

Assuming $C1$ at point $C1a$ cannot detect the pedestrian P , as P is obscured by $T1$. But $C2$ can detect the pedestrian P at point x in time $t1$ and sends the information to $C3$, $C1$ and $T1$. Assuming delay of time t_d in the system thus, $C1$ receives the

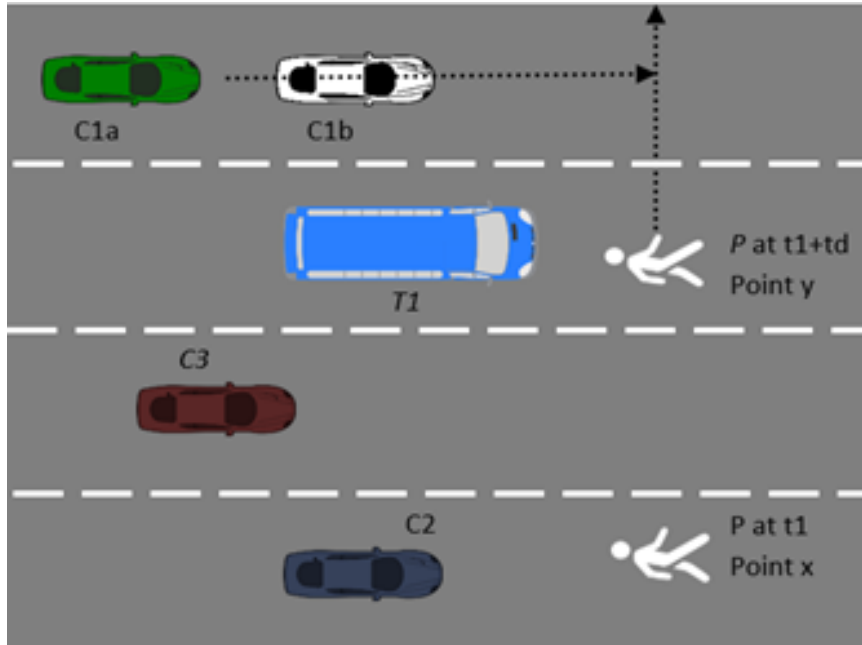


Fig. 3.2. The scenarios of vehicles with V2V-AEB enabled system.

information about the pedestrian at time $t_1 + t_d$. C1 will use this information at which pedestrian was at point x to make a braking decision.

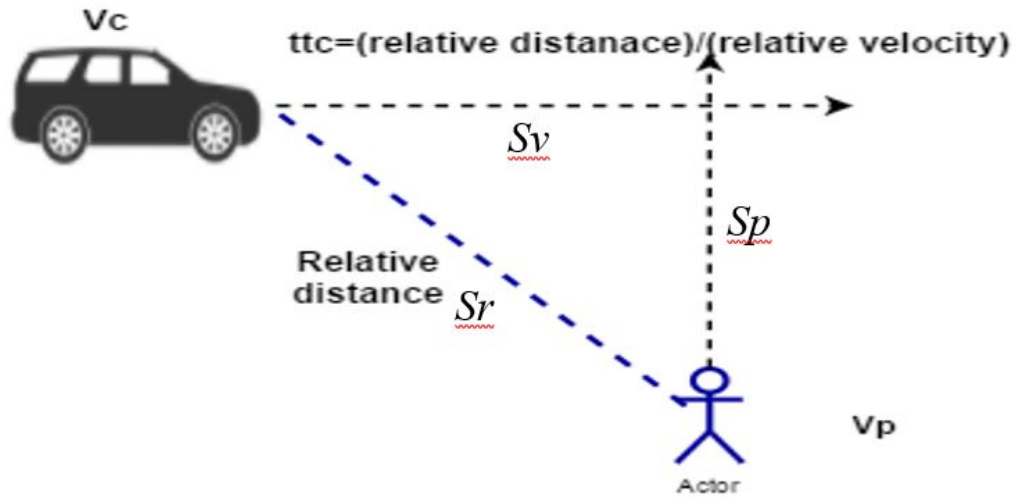


Fig. 3.3. Pedestrian tracking to calculate ttc.

C1 will process the information of the pedestrian and calculate ttc . The ttc and tth is calculated by the equation as follows:

$$tcc = \frac{\text{relative distance}}{\text{relative velocity}} = \frac{S_r}{V_r} = \frac{S_r}{\sqrt{V_c^2 + V_p^2}} \quad (3.5)$$

$$tth = \frac{V_c}{\text{maximum deceleration } a} \quad (3.6)$$

Where,

V_r =relative velocity

V_c =velocity of the car

V_p =velocity of the pedestrian

To make AEB decision, tth is compared with tth to check when the car should start braking. The decision is given to brake when $tth = tth$. As there can be a time delay, t_d , while sending the message, thus actual S_r will be different from calculated S_r , through reported pedestrian location.

Traditionally, current $S_r = \text{original}S_r + \Delta S_r$ is predicted based on t_d and used to calculate accurate tth at every time stamp.

$$\text{original}S_r = \sqrt{S_p^2 + S_v^2}$$

$$\Delta S_p = V_p t_d + \frac{1}{2} a t_d^2 \quad (3.7)$$

Where, ΔS_p is the distance covered by the pedestrian in time t_d

$$\text{current}S_r = \sqrt{(S_p - \Delta S_p)^2 + (S_v)^2} \quad (3.8)$$

By the traditional method, this prediction is needed to predict collision for all pedestrians in every sample time. To reduce the computation, in this paper, we propose to skip this prediction step and use t_d and original S_r directly to make braking decisions such as,

$$tth_c \geq tth \geq tth$$

Let,

$$ttc_c = ttc_o - t_a \quad (3.9)$$

Where,

ttc_c = current time to collision after prediction

ttc_o = original time to collision without prediction

t_a = time difference between original time to collision and current time to collision

Substituting value of ttc_c from equation 3.9 in equation 3.4.

$$ttc_o - t_a \geq tsb \geq ttb$$

$$ttc_o \geq tsb + t_a \geq ttb + t_a \quad (3.10)$$

Thus from eq. 3.10 we can verify that by adding certain time to ttb and tsb we can use the ttc_o derived from an original position of the pedestrian without calculating the current position of the pedestrian. Now, let us explore the relationship between communication delay and tsb such that a potential collision can be avoided, i.e. how can we increase ttb as per delay in the system, to overcome the difference between current ttc_c and original ttc_o .

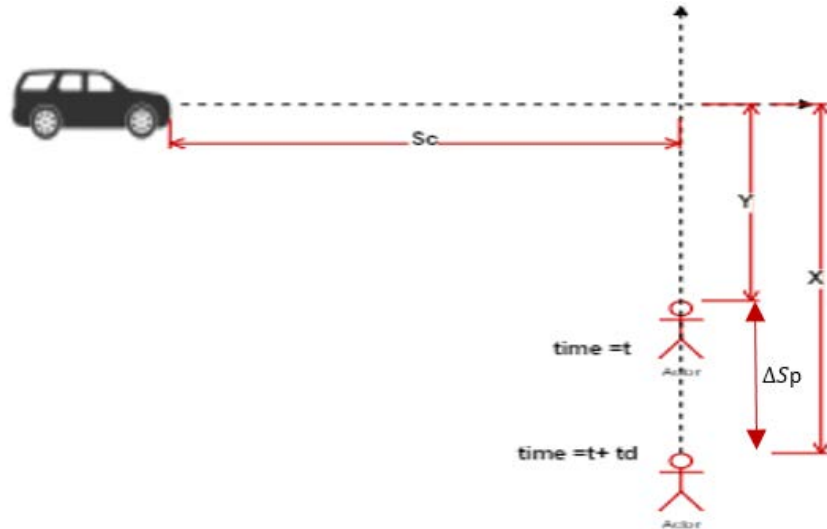


Fig. 3.4. Pedestrian tracking to calculate ttc with and without delay

We can calculate x from the position of the pedestrian so the ttc from eq. 3.5 is.

$$ttc_o = \frac{S_r}{V_r} = \frac{\sqrt{S_c^2 + x^2}}{V_r} \quad (3.11)$$

When there is delay in the system, the actual current position of the pedestrian is y ,

$$y = x - \Delta S_p$$

Where,

ΔS_p is the distance covered by the pedestrian in time t_d , the current ttc from eq. 3.5 will be

$$ttc_c = \frac{S_r}{V_r} = \frac{\sqrt{S_c^2 + y^2}}{V_r} = \frac{\sqrt{S_c^2 + (x - \Delta S_p)^2}}{V_r} \quad (3.12)$$

For active safety feature ttc_c is compared with tth , when they are same, braking is applied. But when the information is delayed, it can be seen the original ttc_o is greater than the current ttc_c . So if ttc_o is compared with tth there will be a delay in making a decision. But if we increase the tth and then compare with the delayed ttc_o , the delay in the decision can be overcome (eq 3.10).

To see that with what proportion of time delay tth should increase, let us see the difference between the current ttc_c and the original ttc_o from eq 3.9.

$$t_a = ttc_o - ttc_c$$

Substituting the value of ttc_c from eq 3.12,

$$t_a = ttc_o - \frac{\sqrt{S_c^2 + (x - \Delta S_p)^2}}{V_r}$$

$$t_a = ttc_o - \frac{\sqrt{S_c^2 + x^2 - 2x\Delta S_p + \Delta S_p^2}}{V_r}$$

$$t_a = ttc_o - \sqrt{\frac{S_c^2 + x^2}{V_r^2} - \frac{(2x\Delta Sp - \Delta Sp^2)}{V_r^2}}$$

From equation 3.11,

$$t_a = ttc_o - \sqrt{ttc_o^2 - \frac{(2x\Delta Sp - \Delta Sp^2)}{V_r^2}}$$

$$t_a = ttc_o - \sqrt{ttc_o^2 - Z}$$

Where,

$$Z = \frac{(2x\Delta Sp - \Delta Sp^2)}{V_r^2}$$

Therefore,

$$t_a = (ttc_o - \sqrt{ttc_o^2 - Z}) \times \frac{(ttc_o + \sqrt{ttc_o^2 - Z})}{(ttc_o + \sqrt{ttc_o^2 - Z})}$$

$$t_a = \frac{Z}{(ttc_o + \sqrt{ttc_o^2 - Z})}$$

Therefore,

$$t_a = \frac{Z}{ttc_o}$$

The braking decision is made when ttb is equal to ttc . So for making decision minimum value of ttc can be ttb for AEB system to work. To get the maximum value of t_a we can substitute ttc_o as ttb .

Since, from equation 3.4 for proper decision making:

$$ttc_o \geq ttb$$

Thus,

$$t_a \leq \frac{Z}{ttb} \quad (3.13)$$

From equation 3.7,

$$\Delta S_p = V_p t_d + \frac{1}{2} a t_d^2$$

For generalization let us assume that pedestrian walk with constant speed that is acceleration is 0.

Therefore,

$$\Delta S_p = V_p t_d$$

Substituting the value of ΔS_p in equation of Z:

$$Z = \frac{2xV_p t_d - V_p^2 t_d^2}{V_r^2}$$

$$Z = \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2} \quad (3.14)$$

Z is of the form mt_d , and when Z is maximum t_a is maximum. Assume, $t_d \neq 0$. $Z \leq 0$ when the pedestrian has already passed the collision point.

As from eq (3.13)

$$t_a < \frac{Z}{ttb}$$

Thus,

$$t_a < \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2 \times ttb} \quad (3.15)$$

From equation 3.10

$$ttc_o \geq tsb + \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2 \times ttb} \geq ttb + \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2 \times ttb}$$

Let,

$$Ntsb = tsb + \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2 \times ttb}$$

Where,

Ntsb= new tsb

$$ttc_o \geq Ntsb \geq ttb + \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2 \times ttb}$$

Thus, new tsb can be given as follows:

$$Ntsb = ttb + \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2 \times ttb} \quad (3.16)$$

$$t_d = \text{Curent time} - \text{time stamp of message} \quad (3.17)$$

Where,

t_d = Time delay in the system which can be found through the time stamp of message.

Suppose, we want to keep some safe distance from pedestrian after vehicle completely stops, assume we keep 'd' meter distance. So to keep the safe distance of d meter, new ttb is calculated as follows:

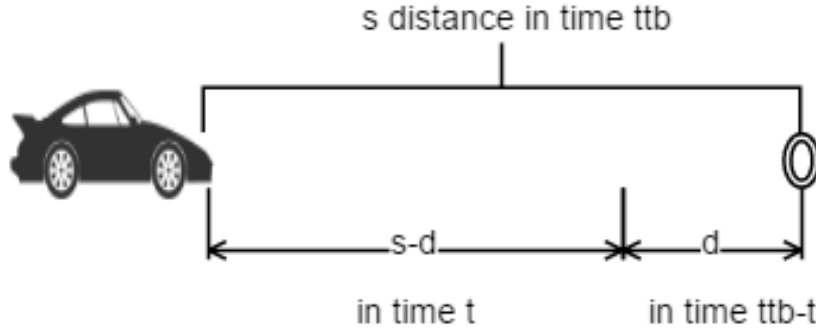


Fig. 3.5. To calculate ttb to stop at a distance (d) before collision

To calculate ttb to stop d distance before a collision, we can consider how much time vehicle will take to travel distance d . Assuming, its initial velocity to be 0,

which will be its final velocity after stopping and considering deceleration of vehicle as acceleration.

$$d = \frac{1}{2}a_m \times ttd^2$$

Where,

a_m =maximum deceleration

ttd =Time to travel d distance

s =distance it travelled after maximum break is applied

$$\text{Time to travel } d \text{ distance, } ttd = \sqrt{\frac{2d}{a_m}} \quad (3.18)$$

Therefore, to stop d distance before collision will be,

$$ttb_s = ttb + \text{Time to travel } d \text{ distance}$$

Where,

ttb_s = ttb to stop d distance before collision

d =distance we want to stop before collision point

Substituting the value of ttb from eq. 3.6 and ttd from eq (3.18)

$$ttb_s = \frac{V_c}{a_m} + \sqrt{\frac{2d}{a_m}} \quad (3.19)$$

Where,

ttb_s = ttb to stop d distance before collision

d =distance we want to stop before collision point

Substituting ttb_s in equation 3.16 in place of ttb

$$Ntsb = ttb + \sqrt{\frac{2d}{a}} + \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2 \times ttb} \quad (3.20)$$

This $Ntsb$ can be used to tackle delay and stop d meter before collision. Let us see in next section how to dynamically change tsb and use equation 3.20 instead of primitive method.

3.2 Algorithm to Reduce Effect of Delay

We have derived how to calculate a time to start braking (eq 3.20) to overcome the delay in the system. We studied that delay in the system changes as the number of pedestrian and vehicle in the system changes i.e. the volume of messages in the system changes. As when number of vehicle and pedestrian in the system changes, the number of message in the system changes, resulting in variation of delay in the system. To tackle this variation, we use the self-evolving system. Whenever the volume of messages in the system change or a new pedestrian is detected, it calculates a *newtsb*.

To calculate the new tsb vehicle checks, if the volume of the message in the V2V network is changed or new pedestrian is detected, indeed if it is. The timestamp of the delayed message is compared with the current time, and the difference of both is used to calculate time delay of the system. In a V2V-AEB system, the car receives information about vehicles in the network and pedestrians detected by other vehicles in the system. If the number of the object received by a vehicle changes, it calculates the time delay. To check the number of objects in the system, a vehicle can use a counter to count the number of messages which describe the volume of the message in the system. If volume increases or decreases, the vehicle will calculate the time delay in the system. As vehicle has the information about the time when the message was generated. Assuming while broadcasting the message in V2V network, the vehicle attaches the timestamp at which the message is generated. If there is a change of time delay in the system, it compares it with the previous time delay in the system. If there is a difference or new pedestrian is detected, it calculates a new tsb.

New time to start braking is calculated as given by equation 3.20:

$$Ntsb = ttb + \sqrt{\frac{2d}{a}} + \frac{t_d(2xV_p - V_p^2 t_d)}{V_r^2 \times ttb}$$

After calculating Ntsb, V2V-AEB system uses it to make a decision through AEB system as shown in Fig 7. The Ntsb is calculated for each pedestrian when it is detected and used to make the braking decision unless the time delay is changed in

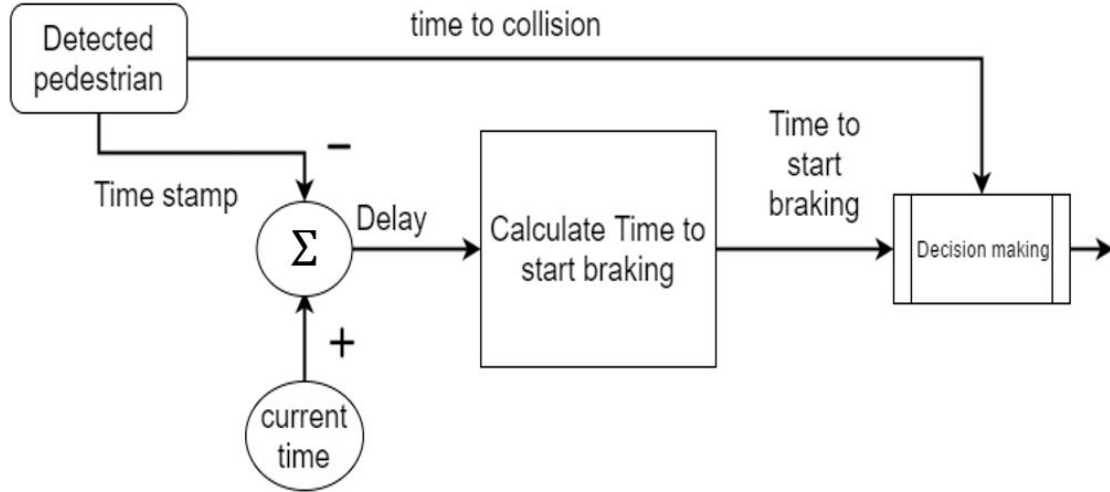


Fig. 3.6. Block diagram to reduce effect of delay

the system. It calculates ttc_o normally from received information without predicting the current position of a pedestrian. As vehicle has the information of x, V_p, V_r no extra computation is required to calculate them.

The algorithm of self-evolving system which is mentioned above is as follows:

Table 3.2.
Algorithm to reduce effect of delay

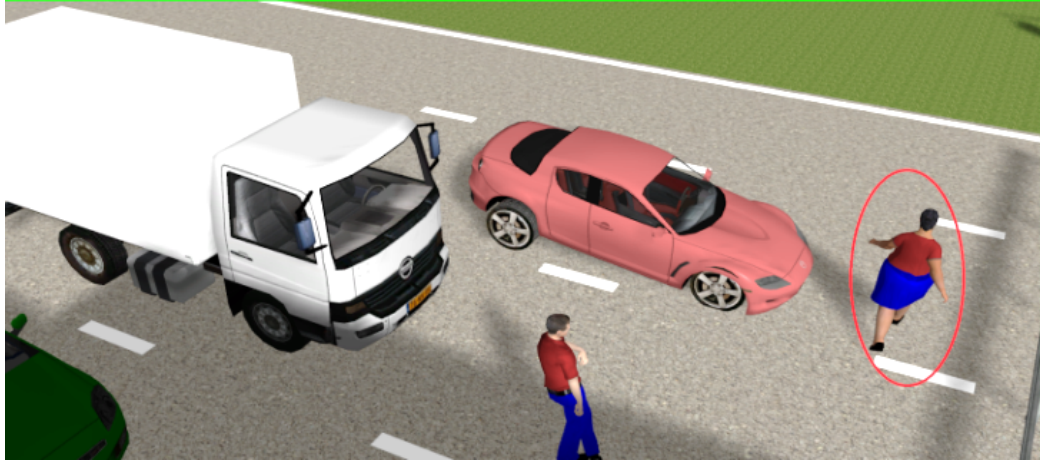
Step 1	Track the change in network load, if there is change go to step 2 or if new pedestrian is detected go to step 3
Step 2	Calculate time delay (eq.15) in the system. If it is different from earlier go to step 3
Step 3	Calculate the $Ntsb(18)$ and send it to AEB system to compare with ttc_o of the respective pedestrian go to step 4
Step 4	When $Ntsb = ttc_o$ make a breaking decision.

3.3 Result

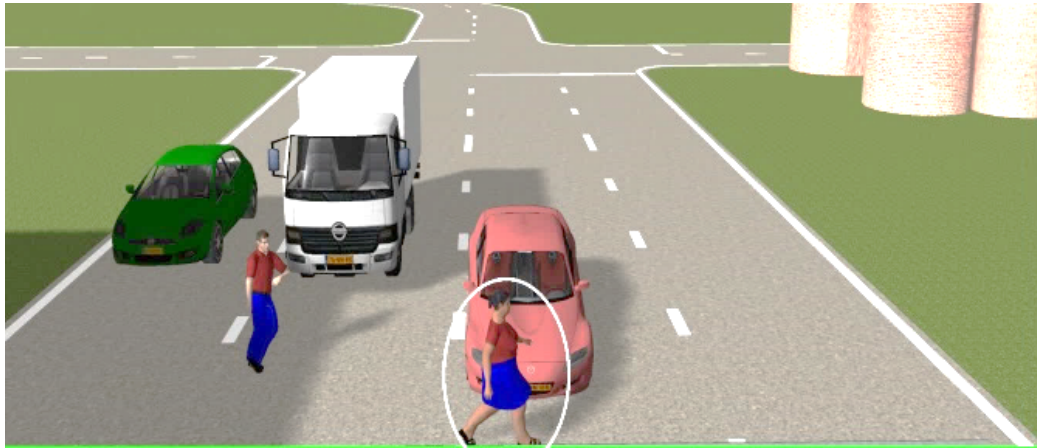
We have stated how the proposed system works to handle the delay in the system. PreScan software is used to demonstrate the algorithms for handling the delay in real system. Following example in simulation helps to see the nature of delay and how it affects the system.

Example: In the scenario as shown in Fig 5, the speed of the car is $14m/s$, the deceleration of the car is $12m/s^2$ and the speed of right and left pedestrians are $1.5m/s$ and $2m/s$, respectively. The truck can detect both pedestrians and broadcast the pedestrian information. The time delay is increased in the simulation to find the M_d .

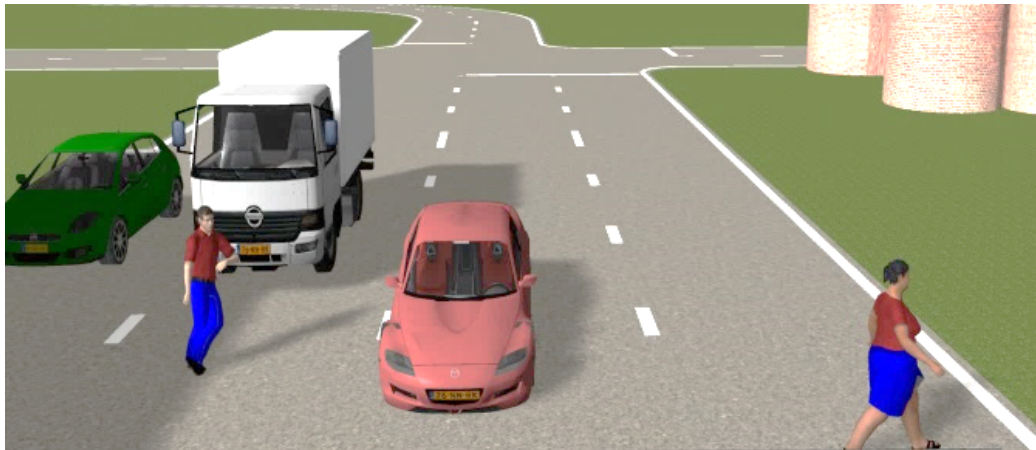
Above figures (Fig. 3.8) shows the working of V2V-AEB system in the ideal condition, i.e., Assuming, no delay in the scenario. The delay in the system is varied for each run in the simulation. The proposed algorithm modulates its time to start braking to overcome the delay in the system. However, it can be seen, that at a particular point no matter how the time to start braking is increased the system fails, i.e., at such point $ttc < ttb$. This delay is termed as maximum delay M_d . From the previous method, the delay which can be handled by the system is less than $0.2s$ in the simulation model. It can be seen that using proposed method we can handle larger delay until its value is lesser than maximum delay. The blue line depicts the delay that can be handled by primitive methods.



(a) Vehicle started applying break using V2V-AEB system



(b) The front view when vehicles started applying break using V2V-AEB system



(c) The front view when pedestrian crossed the road safely

Fig. 3.7. V2V-AEB simulation

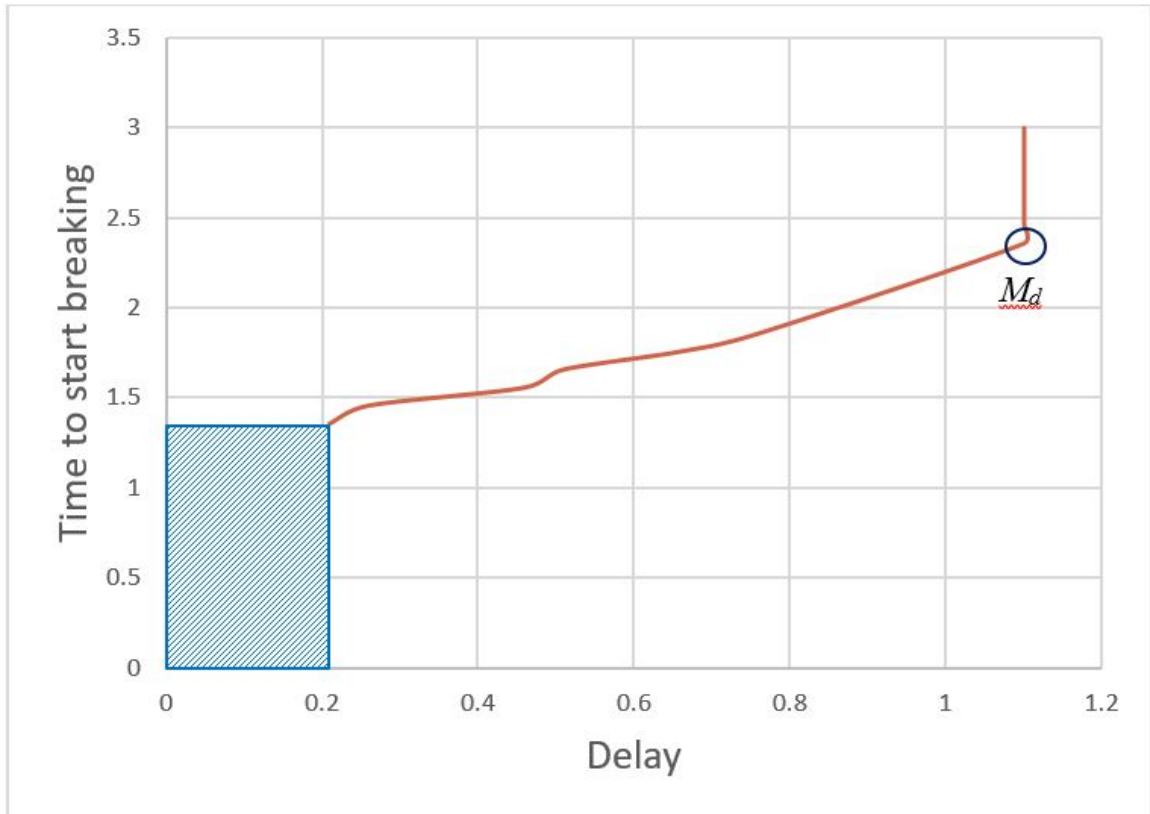


Fig. 3.8. Result of primitive method and proposed method

4. HANDLING DELAY IN V2V-AEB

In the previous section, we formulated a method to reduce the effect of delay in the V2V-AEB system. However, if a delay is above certain point i.e. M_d , the system fails to overcome the delay. To make the proposed system more efficient, the delay in the system should always be less than the threshold value i.e. M_d . As studied in the previous section, the delay is directly proportional to the number of messages. Whereas, a major issue to be tackled in the proposed V2V-AEB system is the message explosion due to a large amount of information available. For example, if there are m cars in a situation and each car identifies n objects, and they create one message for each detected object. Then there will be $m \times n$ messages in the scenario. This many numbers of messages may lead to communication load, which will results in communication delay due to packet collision also processing delay as every car will be required to process $(m - 1) \times n$ messages and processing these many messages needs time.

In this section, we try to answer a question: how to reduce the communication messages and the message processing delay in the V2V-AEB system. In this section, we will also discuss the various method to reduce communication messages and message processing delay in V2V-AEB system [13]. The introduced method prevents sending messages related to the vehicle or pedestrian who is not likely to cause a crash (like the pedestrian who are walking on the footpath or who are standing off the road). The other approach is clustering the pedestrians with related features in a single message, thus reducing the load of messages in the system, which results in the decrease of the communication and message processing delay. We will also discuss message confidence by assigning the level of trust during the time of sending a message.

4.1 Optimizing Vehicle Information

In a V2V-AEB system, the car sends the information about the pedestrian and the vehicle that it detects through its onboard sensor. So it is important to decide which information about the vehicle should be sent and how can we optimize the amount of information without compromising with the efficiency of the system. As if we neglect some important information about the vehicle in the scenario it will lead to some severe accidents and excess of information will lead to increase in the volume of the message in the scenario. This will result in an increase of communication delay and processing delay that indirectly affect the decision making of the AEB system.

A. The question arises how to decide which vehicle information should be sent.

Sending the information about the vehicles which are in V2V network is an excess of information, as more precise information about those vehicles, are already in the network [11]. We assume that the vehicle with the V2V feature shares the information about its speed, location and its movement in the V2V network. Thus sending that information again will be of no use and it will add up to more number of messages. But the question arises to how to decide whether the vehicle is in the V2V network or not?

a. How to decide which vehicles are in V2V network?

There can be several ways for this, like the car capable of V2V communication can have some logo so that other vehicles can neglect to process those vehicles information and to send it in the V2V network. As the vehicles do not have to process any data for this, it will be faster, and it will take $O(1)$ time. But having a logo is not likely acceptable by private car owners.

The other way can be that the vehicle can compare the information from AEB system and those received from the V2V network. If the two vehicles have almost the same information, it can restrain itself from transmitting that information in V2V network. However, as the GPS has some error, we cannot get the exact location of the vehicle. One possible solution is that we can find the similar data having a similar location, speed, and direction. Since vehicles have to process the information, in this case, it will take more time and memory.

4.2 Optimizing Pedestrian Information

The vehicle can detect many objects on the road and roadside. Some pedestrians are just standing or on the roadside that may not cause a potential collision. So it is necessary to separate the information about that pedestrian who can cause a potential collision and who does not. This will enable the vehicle to send the data about those pedestrians that can be injured by the vehicle. So for decreasing the V2V messages about pedestrians, it is necessary to decide which pedestrian causes the potential collision.

The pedestrians walking on the sidewalk can be excluded from the V2V message, as we expect the vehicle will not run on the sidewalk. This will considerably reduce the amount of V2V messages without sabotaging the safety of the pedestrian. However, if a pedestrian is leading towards the road, the vehicle should transmit the data about this pedestrian as it might cause a safety issue.

A. Bifurcating the pedestrian using GPS coordinates:

Assuming that vehicles can get accurate GPS information and road boundary information through on-board sensors, the location and boundary of a road can be obtained out via linking them with Google maps. If the location of the pedestrian or other objects is not on the road, then the car can neglect that object. As soon, GPS will be more accurate to centimeter accuracy [36].

It can be observed from Fig. 4.1 that Google maps can be used to determine the boundaries of roads. So this information about the road can be used to see if the pedestrian is on the road or not.



Fig. 4.1. Location from Google map

B. Eliminating objects not likely to cause collision

a. If a pedestrian is behind a forward moving vehicle on the road, conveying the data of that pedestrian to the vehicle ahead does not improve the safety (See Fig. 4.2). Since the vehicle will not harm the pedestrian at the backside of it Fig. 4.2.

Therefore, a subject vehicle can neglect the received messages from a car behind it. The subject vehicle can also neglect to transmit information of the discovered objects. If there is no vehicle behind the subject vehicle and the detected objects is behind the vehicle in front. However, the question is the outline of no vehicle behind the subject vehicle. As if a vehicle is too far from the pedestrian, then the information of pedestrian is of no use for that vehicle. So it is necessary to decide all those pedestrian whose information car should send. To decide which pedestrian

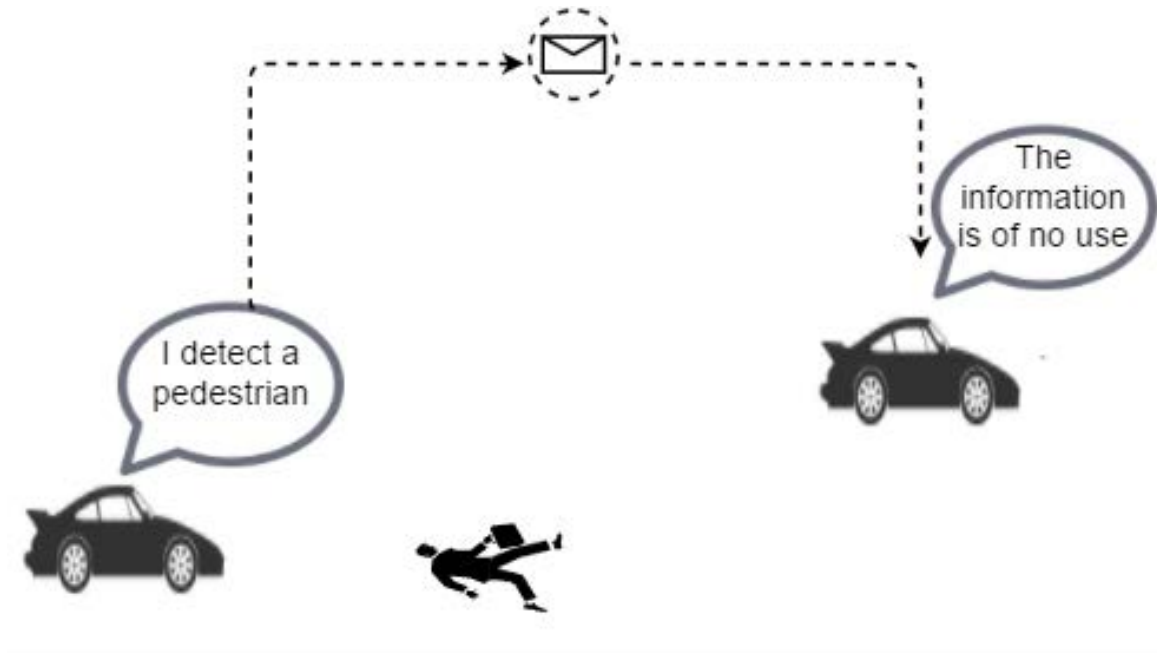


Fig. 4.2. Sending information of the pedestrian in front

information the vehicle should send, it should calculate which pedestrian could cause a collision with other vehicles, and it should send only those information.

1. Calculating which pedestrian information to be sent

In V2V vehicles share their speeds, accelerations, positions, directions over the V2V network. This information is available with a vehicle to decide that, is there any vehicle in the surrounding area which can reach a point where detected pedestrians are crossing the road. If a subject vehicle detects any such vehicle, it should broadcast the message with the pedestrian information.

Let,

V_p = the pedestrian speed

L = length of road pedestrian has to cover

V_v = maximum speed of car

a_v = maximum acceleration of car

T_p = time for pedestrian to cross the road

Thus,

From distance formulae,

$$S = ut + \frac{1}{2}at^2$$

Assuming, the acceleration of the pedestrian is 0

Time for pedestrian to cross the road,

$$T_p = \frac{L}{V_p} \quad (4.1)$$

The maximum distance, S_v , between the vehicle behind the subject vehicle and the detected pedestrian is used to determine if the pedestrian information should be transmitted or not. S_v can be determined by distance formula considering (T_p) (eq 4.1) as a time required by the pedestrian to cross a road and maximum vehicle speed and acceleration.

$$S_v = L \times \frac{V_v}{V_p} + \frac{a_v \times L^2}{2V_p^2} \quad (4.2)$$

Where,

S_v = maximum distance to decide whether to send the message or not

L = lane width

V_v = the speed of vehicle in behind

V_p = speed of pedestrian

a_v = the acceleration speed of vehicle behind the pedestrian

If a pedestrian is crossing the road, and there is a vehicle behind the subject vehicle at a distance less than S_v to the detected pedestrian (eq 4.2), then the subject vehicle should transmit the pedestrian information to the V2V network.

Example 1

The velocity of a pedestrian is 1.2 m/s and four lane road with a width of 3.7 m of lane each lane. The maximum velocity of the vehicle in the road is 80km/hr. i.e. 22.22 m/s and maximum acceleration be $2m/s^2$.

Thus,

$$\begin{aligned} S_v &= L \times \frac{V_v}{V_p} + \frac{a_v \times L^2}{2V_p^2} \\ &= 3.7 \times 4 \times \frac{22.22}{1.2} + \frac{1 \times (3.7 \times 4)^2}{2 \times 1.2^2} \\ &= 426.15 \text{ meter} \end{aligned}$$

So, if a vehicle finds any other vehicle in the range of 426.15 meters in V2V network, it can transmit the information about the pedestrian.

However, if there are many pedestrians and vehicle in the system, the processing time to process all the information will be large. To tackle this problem, we can select the pedestrian with minimum speed, as that will be the maximum time if one starts with minimum speed to cross the road. The other question arises how to select the value of V_v and a_v . Similar to pedestrian speed we can select the V_v as the maximum value of vehicle velocity in the scenario and a_v as maximum acceleration value of the vehicle to get maximum distance.

Example 2

A pedestrian is crossing a four-lane road at a speed 1.2 m/sec. The width of each lane is 3.7 meter. The maximum velocity among all the vehicles behind the subject vehicle is 80km/hr (22.22 m/s), and the maximum acceleration among all the vehicles be $2m/s^2$ Thus, from eq 4.2

$$\begin{aligned} S_v &= L \times \frac{V_v}{V_p} + \frac{a_v \times L^2}{2V_p^2} \\ &= 3.7 \times 4 \times \frac{22.22}{1.2} + \frac{1 \times (3.7 \times 4)^2}{2 \times 1.2^2} \\ &= 426.15 \text{ m} \end{aligned}$$

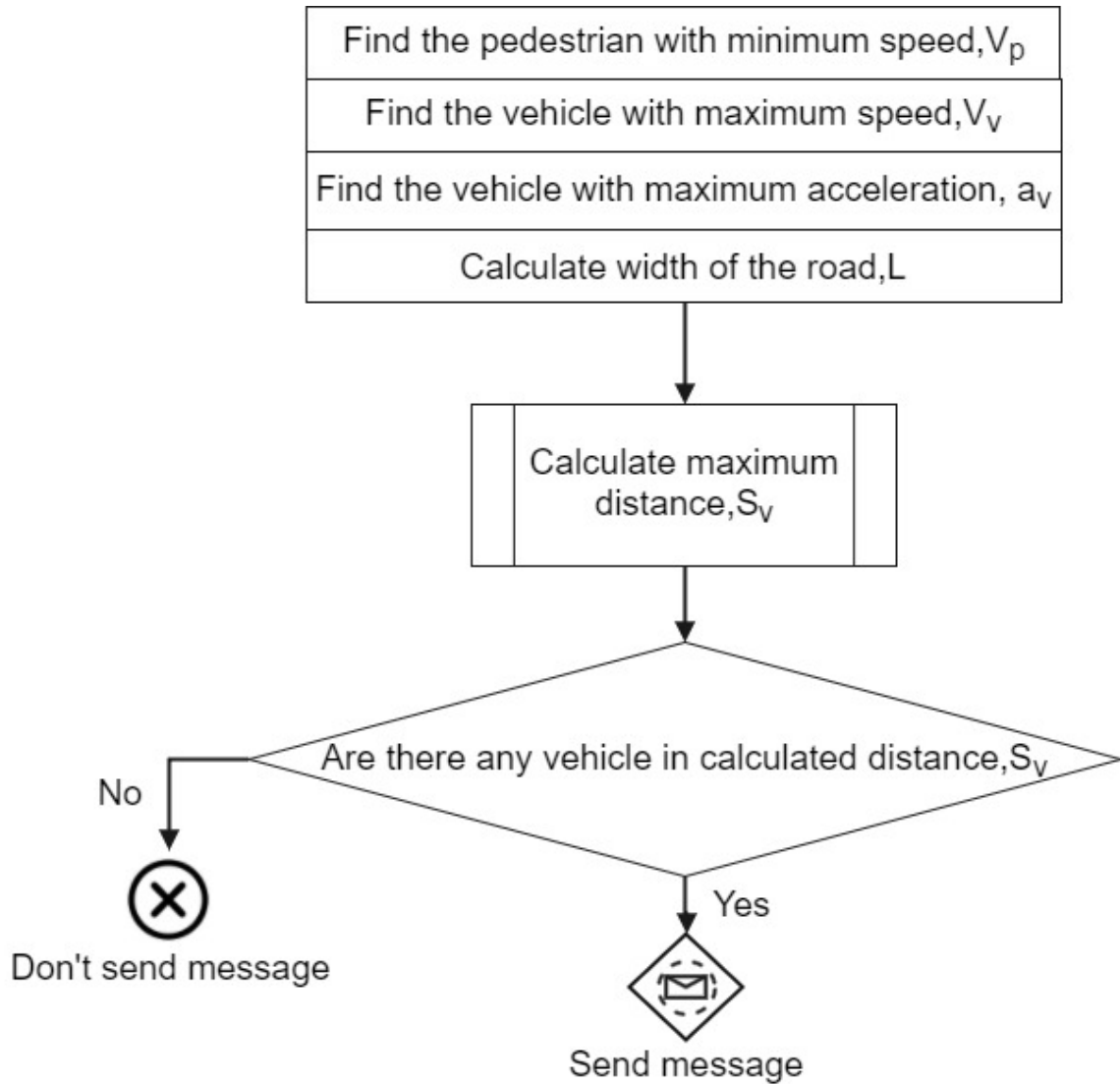


Fig. 4.3. Block diagram to determine which pedestrian information should be sent

So, if a vehicle detects any other vehicle in the range of 426.15 meters in V2V network, it can transmit the information about the pedestrian.

Table 4.1.
Algorithm to determine which pedestrian information should be sent

Step 1	Calculate width of lane, L .
Step 2	Find minimum speed of pedestrians detected, V_p . Maximum speed of vehicles present in the scenario, V_v and maximum acceleration a_v of vehicles. Find minimum speed of pedestrians detected, V_p . Maximum speed of vehicles present in the scenario, V_v and maximum acceleration a_v of vehicles.
Step 3	Calculate maximum distance S_v ,using value calculated from step 1 and 2 Where, $S_v = L \times \frac{V_v}{V_p} + \frac{a_v \times L^2}{2V_p^2}$
Step 4	Find if there is any vehicle in the calculated maximum distance.
Step 5	If step 4 is true broadcast the message.

4.3 Grouping of Pedestrians

In V2V-AEB, each vehicle sends the data about the pedestrians they have detected along with their vehicle information. Analyze a scenario of m V2V-AEB enabled vehicles and n pedestrians at a road intersection. If each vehicle can detect all pedestrians and broadcast them to the V2V network, then each vehicle will receive $(m-1)n$ messages. The receiver vehicle has to process all these messages to make a safety decision. To reduce the number of messages, we suggest a method to cluster the pedestrian information in groups before transmitting them. Thus, reducing the processing time of the vehicle on the receiver side and the communication delay due to packet collision in V2V network.

For clustering these pedestrians, we cannot compromise the safety. Pedestrians having similar information can be grouped as one pedestrian such that all pedestrians will stay in a group until the time they cross the road safely so that they can be viewed as one entity.

4.3.1 Working of the system

To group the pedestrian, we use a clustering technique. If the distances between two pedestrians are less than a predefined threshold 'a', and difference in their speed is less than 'b', then they are grouped in one cluster. The pedestrian information is transmitted as a single pedestrian with the speed of minimum one which ensures us all the pedestrian will cross the road safely and as one entity. The value of a and b are selected such that pedestrian will remain in the same group until they cross the street safely.

When a pedestrian is detected, we measure its distance from the detecting vehicle and thus evaluate its position in an x-y plane before converting it into GPS coordinate as shown below.

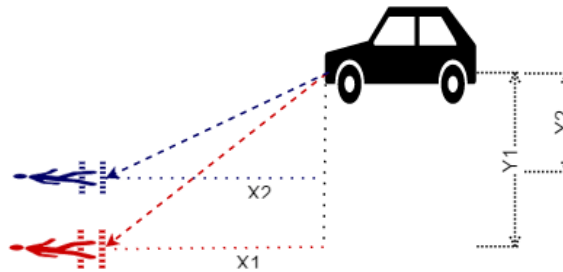


Fig. 4.4. Pedestrian detection by the vehicle

After calculating the x, y coordinate, velocity, and orientation of pedestrian, the information is embedded in a matrix form.

To transmit the data of pedestrians as a group, it arranges the pedestrians in ascending order as per their positions in the y-axis. The first pedestrian is selected from the list and made as a hub. Then the pedestrians are selected and formed as

Table 4.2.
Matrix for pedestrian information

Pedestrian	Location (x)	Location (y)	Velocity	Direction
1	x1	y1	v1	D1
2	x2	y2	v2	D2
3	x3	y3	v3	D2
4	x4	y4	v4	D1
5	x5	y5	V5	D2

a group whose distance from the hub is less than or equal to threshold a , difference between their speeds is less than the threshold b and they are moving in the same direction. Similarly, all the groups are created. The grouped pedestrian is transmitted as the single entity with the average location of the pedestrians in the hub and the lowest velocity among all the pedestrians in the hub. Before broadcasting the information, the location is converted in the form of GPS coordinates.

As the pedestrian are arranged in ascending order of their y location, when we discover the distance of a pedestrian to another pedestrian in the same hub is greater than a , a new hub is created to other pedestrians. This process iterates until all pedestrians are grouped.

Example 3

The example in Figure 7 shows how the ten pedestrians are grouped using the proposed algorithm. Figure 7 represents the data array (dashed box) of the proposed algorithm. X s represent the pedestrian by parameter (x , y , and v), where x is its location in the x -axis, y in y -axis and v is its speed. The pedestrian is arranged in ascending order, according to its location in y -axis in an array (dashed box).

After arranging the pedestrians, the hub of the group is greedily selected in each iteration. The pedestrian whose location difference is less than or equal to 1 meter

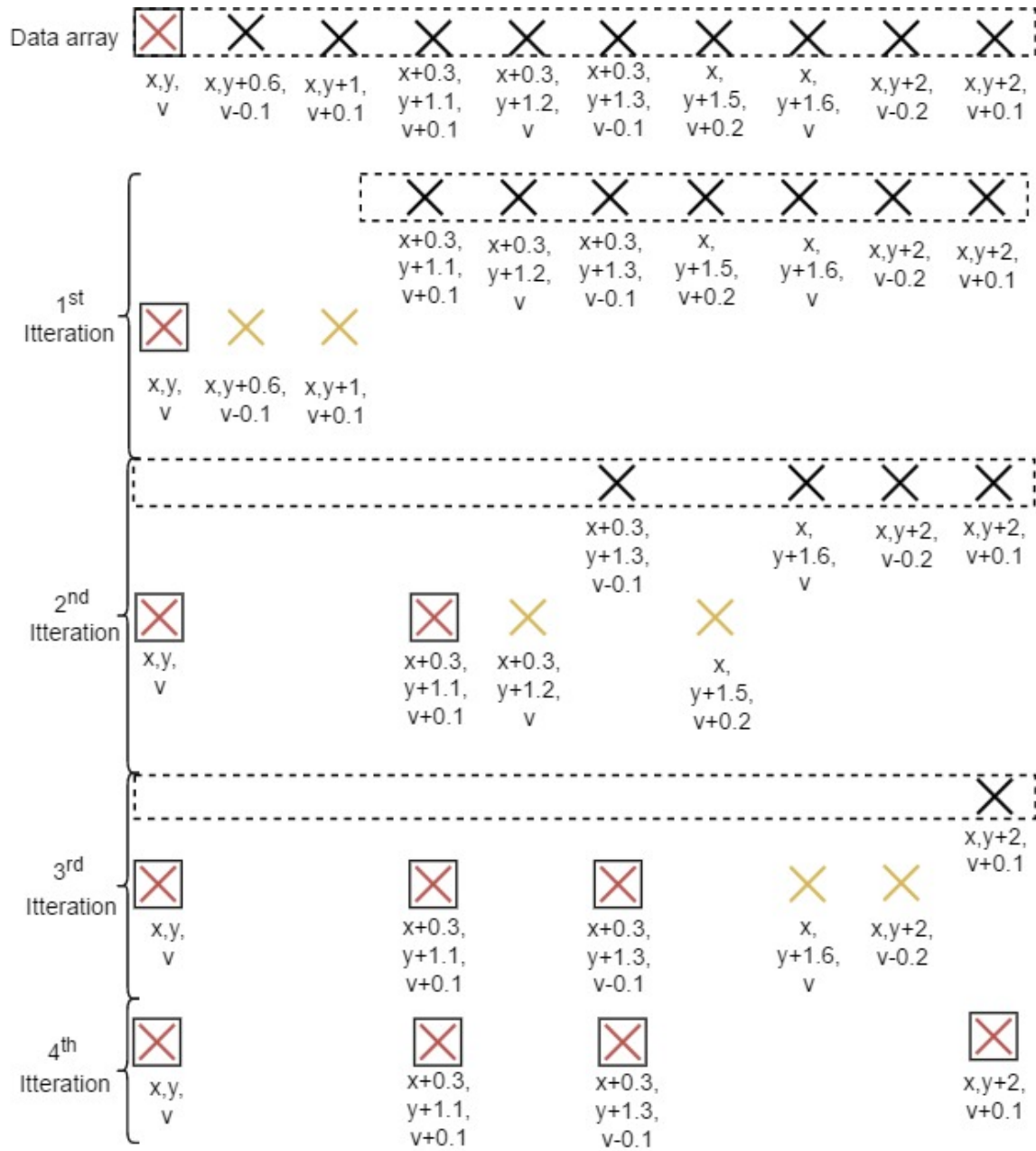


Fig. 4.5. Example of pedestrian groping

and the magnitude of the difference between speed is less than equal to 0.1m/s is included in the group of the respective hub as described below.

In iteration 1:

The first element of the array is created as a hub. The box with a solid line represents the group.

The pedestrians are selected whose distance, $d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$ is less than 1 meter and difference of speed is less than or equal to 0.1m/s with respect to the hub. Yellow X denotes the selected pedestrians i.e. 2nd and 3rd pedestrian, red X denotes the hub, and the group is indicated by a box with a solid line. When no pedestrians are left in an array whose distance is less than 1 meter and speed is less than or equal to 0.1 m/s a new hub is created, and similarly, pedestrians are selected. As we see that distance 4th pedestrian from the hub is 1.14 meter which is greater than 1 meter. Thus it is not included in the group.

In iteration 2:

After completion of iteration 1 when no other pedestrian belongs to group 1. The new pedestrian is selected as a hub from the array, i.e., pedestrian 4. The other pedestrians (pedestrian 5 and 7) are selected to form a group as explained in iteration 1. It can be viewed, the difference of pedestrian (pedestrian6) velocity (-0.2 —m/s) is greater than 0.1m/s to the hub. Thus it is not included in the group.

In iteration 3:

Pedestrian 6 is selected as a new hub as it does not belong to any other group. The other member (pedestrian 8 and 9) of the group is selected, similarly from the array as described in iteration 1.

In iteration 4:

The 10th pedestrian does not belong to any other group. Thus, it is made as a new hub.

The information about the hub is sent over V2V-AEB network; it is demonstrated by the solid box. For the above example, ten pedestrians are grouped in 4 groups after 4th iteration as seen above and the information is broadcasted when the array is empty.

4.3.2 Result

Figure 9 shows the output for grouping of the pedestrians in the example. Each blue dot indicates one hub whose information is transmitted through the V2V network.

The 24 pedestrians were grouped into eight groups by the algorithm. Suppose these 24 pedestrian and 20 cars are on the road, by using the grouping algorithm, we can reduce the number of messages from 480 to 160. Thus on the receiver side instead of processing 480 messages, it just has to process this 160 messages.

The sender side needs to process the 24 pedestrians to form groups and convert the location of the hub of groups to GPS coordinates. Then the GPS locations can be broadcasted over the V2V network.

4.4 Jamming of Network

There might be cases when there are many pedestrians on the road. For example, around 14,000 pedestrian walk in one hour near west 34th street as per 2015 studies [37]. Also, according to reports [37], there were as many as 55 pedestrian fatalities. If all the information is shared over the V2V network, it will cause network overload, leading to the large number of packet collision, communication delay, and message processing delay. Thus, if there are too many pedestrians in the environment, the

Fig. 4.6. Algorithm for clustering

Note: ► *This represent comment*

Step1 Differentiate pedestrian as per their directions of crossing the road (here we consider 2 directions whether pedestrians are moving left or right with respect to vehicle, as most of the pedestrians on the road try to cross the road. thus they will come in this category. Other pedestrians who are not in this category can be sent as an individual entity)

Step 2 Arrange pedestrian in increasing order of their location in y axis with respect to the vehicle.

Step 3 Select the first pedestrian (minimum location) from the array and make it as a hub. Total number of hubs, $m=1$.

► *m is the counter to count number of hubs*

Step 4

For $i=2$ to total number of pedestrians in the same direction of crossing the road

Calculate distance of pedestrian[i] from the hub

Calculate speed difference of pedestrian[i] and that of the hub

If (distance > a or difference of speed > b)

total number of hub is $j=m$,

► *j is a memory used to store the number of hubs to use it as counter. So that, the information about total number of hubs is not lost*

while($j \geq 1$)

Calculate distance of pedestrian[i]

from hub[j]

Calculate speed difference of

pedestrian[i] with hub[j]

If ((distance < a) and (speed < b))

exit if loop

► *it exit the loop as the pedestrian belongs to already existing group.*

else

$j=j-1$

end if else loop

end while loop

Add as a new hub

$m=m+1$;

end if loop

end for loop

► *Repeat step 4 for every direction*

Step5: Broadcast all the hub information over DSRC network

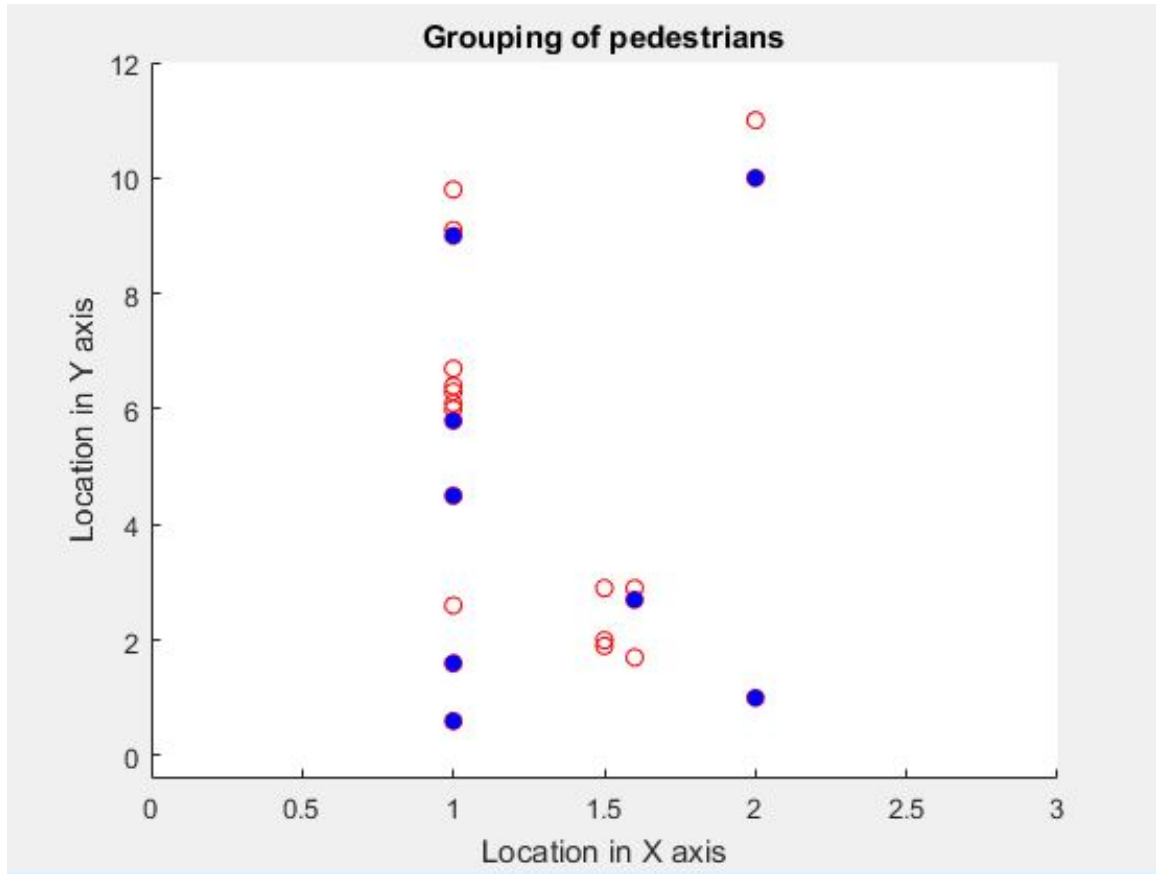


Fig. 4.7. Grouping of pedestrians using MATLAB (blue dots indicate the hub)

best option will be preventing vehicle to send pedestrian messages (except in critical emergency conditions such as medical emergency condition) over V2V network, to avoid congestion in the network.

Therefore, the question arises what is the maximum number of pedestrians detected that vehicle should stop sending pedestrian messages. However, it will not be appropriate to select based on the number of pedestrians, because it might be possible that just one vehicle can detect all pedestrians, whereas the pedestrians are not in the line of sight of other vehicles. In this case, information from the vehicle who can detect all the pedestrians is critical. So instead of determining the number of pedestrians, we use the time delay in the network to decide whether a vehicle should

broadcast message of observed objects or not. When the network is congested and the time delay in the system is such that no safety decision can be made in time to benefit safety by using received information through V2V network, the vehicle can stop sending messages of observed objects.

That is,

$$t_d \geq \text{Maximum delay}, M_d$$

Such that,

$$ttc < ttb$$

Where,

Maximum delay (M_d): the threshold time delay above which the AEB system cannot avoid collision.

ttc = time to collision i.e. time when the car will collide with the object.

ttb = threshold time for braking, i.e. minimum time required by the vehicle to stop the car.

$$t_d = \text{time delay} = \text{Current time} - \text{time stamp}$$

Therefore, the vehicle can stop sending messages when the time delay in the system is above maximum delay and will continue sending the message only when a delay of the system becomes lower than the maximum delay.

The introduced method can be executed as shown below (see Figure 4.8). The received message from V2V-AEB message has the information about when the message is generated. The time stamp from the received message is compared with the current time to calculate the delay in receiving the message. If the calculated delay is found above maximum delay, the vehicle does not construct the V2V message to broadcast the object detected by its onboard sensor over a V2V network. Where, maximum delay is the threshold time delay above which the AEB system cannot avoid a collision, i.e., when time to collision to an object is greater than a threshold time for braking (i.e. the minimum time required for the vehicle to stop).

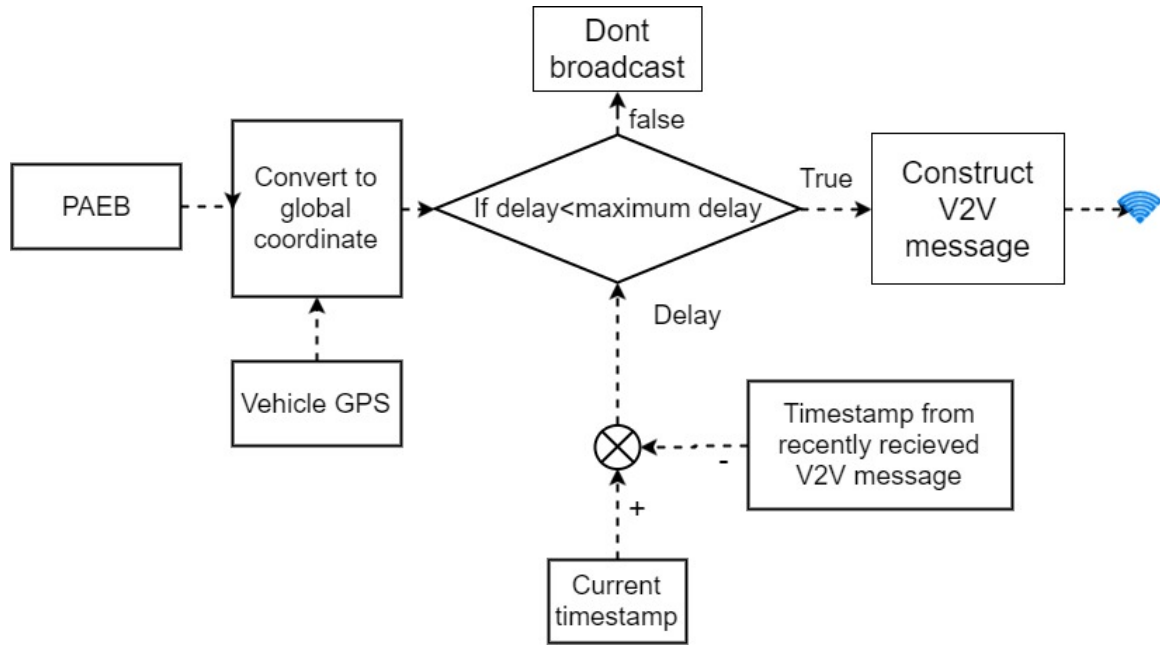


Fig. 4.8. Block diagram to reduce jamming of the network

4.5 Message Confidence

It is also necessary that the pedestrian information accuracy is considered while sending the message. We termed it as Message Confidence.

The accuracy of the information of the pedestrian depends on how close the object is to the radar and camera and also the efficiency of the radar. We assume that the company provides the efficiency of its radar in the form error per meter. Suppose the range of the radar to detect pedestrian is from 0.15 m to 20 m and the error is 0.1 per meter. So we take the mean to be 10 meters assuming if the pedestrian is in the range of 10 meter its information is almost correct.

To calculate the pedestrian confidence we divide ten by the range of pedestrian to the car i.e. suppose the pedestrian is 12 m away from the car then its confidence is $\frac{(10-0.1 \times 10)}{12} \times 100 = 83.33\%$ If it is less than 10 meter, its pedestrian confidence will be greater than 100%. If the pedestrian confidence is greater than 100, we will round it to 100% So the confidence of the message can be calculated as follows Percent confidence = $M(1-E)/D * 100$ M= mean of the range E= error of the radar in the form error per meter D=distance of the object from the radar

5. CONCLUSION AND FUTURE WORK

5.1 Conclusion

The proposed algorithm can detect emergency condition by monitoring pulse rate of the driver. During an emergency condition, the health monitoring system triggers the vehicles V2V-AEB system. The V2V-AEB system helps the patient to park vehicle safely and broadcast the emergency signal over the V2V network. It is necessary to personalize the algorithm because every individual has different pulse rate pattern. To tackle this condition, the algorithm is made adaptive to personalize as per the user. The attribute for the system is extracted using five healthy person and eight patient data, and it is tested on ten patient data and four healthy persons data. Also, the pulse rate changes as per the activity user are performing. To identify activity user is performing KNN algorithm was used which gave the accuracy of 87.1%. The time complexity of KNN is $O(nk+nd)$ (where n is the total number of data, k is the nearest neighbor on whose bases activity is predicted, and d is the time required to calculate the distance between 2 points). To reduce the time complexity 2nd standard deviation is used as a boundary line of the acceleration value for 3 activities (running, resting, walking) with an accuracy of 78%. Then as per the activity user is performing the pulse rate is monitored to detect the cardiac emergency condition.

In the third section, we studied the effect and reason of delay in V2V-AEB system. It has been studied that delay is directly proportional to a number of message in the system. We have proposed a new method to tackle this delay by increasing the time to start braking, unlike primitive method to extrapolate trajectory of a pedestrian at every time stamp.

Instead of just assigning one number as a time to start braking, the system can calculate the time to start braking as per delay in the system. Using the proposed algorithm, we can handle large value of delay compared with the primitive method as shown in the results. Thus making the system robust, as it will minimize the effect of delay.

However, if the delay is large precisely at the point when time to collision is lesser than a threshold time for braking the proposed system also fails. Thus to make a system more efficient, the delay in the system should always be kept below the threshold value. The proposed system helps to reduce communication delay and processing delay in the system by reducing the number of message in the V2V-AEB network. Thus, it increases the chance that V2V-AEB system makes the decision on time. Using the method of elimination, information about some pedestrians are not sent if they are not on the road or there is no vehicle in the range to cause a potential collision. Further, the proposed method of grouping is tested in a simulation with 24 pedestrians which were grouped into eight groups. We also discussed the method to prevent V2V network jamming, by monitoring delay in the network.

5.2 Contributions

The focus of this research is to develop an Intelligent cardiac monitoring system and integrating with the V2V-AEB system. The developed intelligent cardiac monitoring system tracks acceleration sensor data and pulse rate to predict heart attack of the driver. Datasets of healthy persons and heart attack patients are used to test the developed system. The system is also tested in real time using FRDM-K64 and a heart rate sensor module. The data of the pulse rate is sent to the cloud using an IOT platform provided by the AT&T company. The integration of the cardiac monitoring system with the V2V-AEB system is simulated using PreScan. The pulse rate of the heart patients is fed in the simulation to test the heart attack cases while driving.

Since there will be a large number of messages in the proposed system, it may lead to delay and network congestion. The delays are one of the main constraints in V2V-AEB system as it is a real time system. A method is proposed to handle this delay in the V2V-AEB system by changing vehicles time to start braking as per delay in the scenario. The proposed system is mathematically proved and tested in the simulation. However, if the delay in the system is above certain value such that time to collision is less than time to start braking the proposed system to handle delay fails. Therefore it is necessary to keep delay under a certain value i.e. M_d . Various methods to reduce delay and network congestion have been formulated and implemented in the simulation.

5.3 Future work

The further extension of this project can be to detect the drowsy condition of the driver. It can also determine if a person is intoxicated due to alcohol consumption. To increase the accuracy of the predictions we need to train this network with different datasets containing different demographics and conditions. BMI is the body mass index, which is an important factor in analyzing the users health condition. Also, we can include inputs such as if a person is a smoker or non-smoker and manipulate the pulse rate setting and the time we wait to observe the patients data could be reduced in such cases. Various other factors are required to include in the code, and one of the inputs that user gives would be his previous medical history where he needs to enter if he has had conditions such as, asthma, high or low blood pressure, any cardiac arrests, etc. Depending upon such conditions, the program needs to be trained to sense any irregularities and make desired decision.

The algorithm to reduce the effect of delay in the system can be advanced by considering weather condition and storing the performance of the vehicle at various scenarios. Other advance methods such as neural network can be used to get more precise values.

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